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Background Atmosphere Radiance Day (BARD) and Night (BARN)

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P.O. Box 7957
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13. ABSTRACT *(Maximum 200 words)*

This document describes the format, the details, and methods used to calculate the BACKGROUND ATMOSPHERE RADIANCE DAY (BARD) and NIGHT (BARN) data bases. BARD/BARN (v4.1), in tabular ASCII form, consists of 57 bins, each 5% in energy, spanning 1.9 to 34μm. BARD/BARN (v4.1) is now available and is being used within fast running codes such as IRSim, HISEMM, and SCENARIO. ARCHON was used to determine the non-local thermodynamic equilibrium quantum state populations for tangent altitudes starting at 40 km up to 200 km. The radiation transport code NLTE was then used to determine the line-of-sight radiance within each bin for the 75 transitions occurring for CO_2, H_2O, CO, NO, and O_3. For LTE atmosphere, MODTRAN was used for the tangent altitudes from 60 km to 0.1 km. The procedure merging the overlapped portions of the NLTE and LTE data is described. Graphical representations of the BARD/BARN data is appended for user reference.

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PREFACE

We wish to thank Dr. Tim Stevens of PRi Huntsville for his help defining the requirements and parameter definition for BARD/BARN. We also wish to thank Dr. Ken Schwartz of DNA/RAAE for his encouragement and support of this effort.

CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement

MULTIPLY ⟶ BY ⟶ TO GET
TO GET ⟵ BY ⟵ DIVIDE

angstrom	1.000000 × E -10	meters (m)
atmosphere (normal)	1.01325 × E +2	kilo pascal (kPa)
bar	1.000000 × E +2	kilo pascal (kPa)
barn	1.000000 × E -28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054350 × E +3	joule (J)
calorie (thermochemical)	4.184000	joule (J)
cal (thermochemical) / cm^2	4.184000 × E -2	mega joule/m^2 (MJ/m^2)
curie	3.700000 × E +1	*giga becquerel (GBq)
degree (angle)	1.745329 × E -2	radian (rad)
degree Farenheit	$t_K = (t_F + 459.67)/1.8$	degree kelvin (K)
electron volt	1.60219 × E -19	joule (J)
erg	1.000000 × E -7	joule (J)
erg/second	1.000000 × E -7	watt (W)
foot	3.048000 × E -1	meter (m)
foot-pound-force	1.355818	joule (J)
gallon (U.S. liquid)	3.785412 × E -3	meter^3 (m^3)
inch	2.540000 × E -2	meter (m)
jerk	1.000000 × E +9	joule (J)
joule/kilogram (J/kg) (radiation dose absorbed)	1.000000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448222 × E +3	newton (N)
kip/inch^2 (ksi)	6.894757 × E +3	kilo pascal (kPa)
ktap	1.000000 × E +2	newton-second/m^2 (N-s/m^2)
micron	1.000000 × E -6	meter (m)
mil	2.540000 × E -5	meter (m)
mile (international)	1.609344 × E +3	meter (m)
ounce	2.834952 × E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448222	newton (N)
pound-force inch	1.129848 × E -1	newton-meter (N·m)
pound-force/inch	1.751268 × E +2	newton/meter (N/m)
pound-force/foot^2	4.788026 × E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535924 × E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4.214011 × E -2	kilogram-meter^2 (kg·m^2)
pound-mass/foot^3	1.601846 × E +1	kilogram/meter^3 (kg/m^3)
rad (radiation dose absorbed)	1.000000 × E -2	**Gray (Gy)
roentgen	2.579760 × E -4	coulomb/kilogram (C/kg)
shake	1.000000 × E -8	second (s)
slug	1.459390 × E +1	kilogram (kg)
torr (mm Hg, 0° C)	1.333220 × E -1	kilo pascal (kPa)

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

TABLE OF CONTENTS

SECTION 1
INTRODUCTION

1.1 OVERVIEW.

There are many engagement or engineering-level atmospheric radiance calculations whose main requirements are fast run-times and moderate fidelity/resolution. This is especially true in "scoping" systems operability issues, evaluating operational parameters or investigating phenomenology radiance contrast ratios. Although such calculations must be physics-based and traceable to "first-principles" codes, the requirements can often be met with analytic algorithms supported by pre-calculated data bases.

One of the prime drivers for understanding nuclear radiance effects on systems operability is the contrast ratio of the nuclear-enhanced atmospheric radiance to the ambient radiance. To support the evaluation of this contrast ratio, an ARCHON-based tabular compendium of the radiance characteristics of the ambient day/night earthlimb atmosphere has been assembled. This compendium is called "Background Atmospheric Radiance - Day (BARD) and Background Atmospheric Radiance - Night (BARN). The data represents space-to-space earthlimb radiance vs altitude profiles from hard-earth to 200 km covering the spectral region 1.9μm - 34μm, in 5% energy bins.

In this report, we discuss the methodology and details used in deriving the compendium and the form and format of the data bases. We also include graphical representations of the atmospheric radiance profiles described by the compendium along with examples of data base validation against the SPIRE[8] atmospheric radiance measurements experiment.

1.2 PHILOSOPHY.

The BARD/BARN data bases were originally intended for use with DNA models such as IRSim and HiSEMM, as well as to support more robust codes such as SCENARIO and NORSE for fast and moderate fidelity/resolution descriptions of the ambient atmosphere. However, BARD/BARD were generically formatted so that their access and use for a broad range of applications would be relatively easy.

An essential aspect of this effort is performance of the computationally difficult ambient atmospheric calculations "up front" so that the end users are not required to perform them for each scenario desired. Providing comprehensive data bases in tabular format requires a minimum of user manipulation or programming to obtain sensible results. No analytical assumptions have been made in generating the chemical dynamics basis for the data bases. We have used the first-principles code, ARCHON[5], with detailed physical/chemical

descriptions of the ambient atmosphere, coupled to the Phillips Laboratory/Geophysics Directorate line-by-line radiation transport code, NLTE[12], for the higher-altitude radiance calculations. For lower altitudes, we have used the community-accepted MODTRAN[4], a derivative of LOWTRAN 7[6], for radiance calculations. This approach lends confidence that the BARD/BARN data base is an accurate representation of the "real" ambient atmosphere. Comparison to experimental data, where applicable, was used to validate the approach and results. At the time of project initiation, the comprehensive SHARC code[11] (v2.0) was not available. Thus the approach was to use the ARCHON/NLTE combination (described below) to derive the radiance values. For continuity, this methodology will continue to be used for updates but periodic cross-checks with SHARC 2.0 will be accomplished both for BARD/BARN verification and to establish cross-code comparisons.

An additional aspect of this effort was the early delivery of intermediate versions of the data bases to end-users while continuing to refine the calculations. For example, a preliminary version of BARD was given to PRi in November 1990 for use in meeting an immediate IRSim model requirement. A series of refinements to BARD/BARN resulted in the lastest BARD/BARN (v4.1) being placed into general release in early March 1991. BARD/BARN v4.1 has been delivered to the IRSim, HiSEMM, SCENARIO and SSGM groups for their use. Refinements and code upgrades continue to be developed and subsequent BARD/BARN versions will be periodically released to meet new requirements.

SECTION 2
METHODOLOGY

2.1 DATA BASE GENERATION, FORM AND FORMAT.

The codes used for data-base generation are ARCHON/NLTE for the non-local-thermodynamic-equilibrium (NLTE) part of the atmospheric earthlimb and MODTRAN for the local-thermodynamic-equilibrium (LTE), part of the atmospheric earthlimb. These codes are described in detail elsewhere[4,5,12] and are only synopsized below. The basic difference between LTE and NLTE is that in LTE, the population of the vibrational levels giving rise to the radiance is defined by the local kinetic temperature. Under NLTE conditions, this criteria is not valid, and detailed chemical dynamics calculations must be performed to accurately describe the vibrational level populations. The transition from NLTE to LTE occurs nominally in a range around ~50 km but it is not uniform and varies with day/night and wavelength. Some assumptions have been made to describe the transition region in this version of BARD/BARN. These assumptions are discussed below.

A convenient means to present the data is to integrate the spectral radiance over pre-specified wavelength ranges. For this release, we have followed the NORSE approach, which typically defines a series of spectral "bins", each with spectral resolution 5% of the central wavelength. The bins are defined starting with a central wavelength of 2 μm and including 2.5% of the bin energy either side of the central wavelength. Using this definition, 57 bins of varying spectral sizes were constructed up to the last bin center at 30 μm. Table I shows the 57 resulting parameter sets that spectrally define each bin.

The altitude resolution of the data base varies. At lower altitudes (1-40 km), where the radiance profile is complex, the altitude resolution is 1 km. The resolution increases at 40 km to 5 km increments up to the limit of 200 km. Thus each spectral bin is associated with 72 altitude calculations. The data base itself is an ASCII formatted three-column file organized by *decreasing* altitude, bin central wavelength and radiance. Table II illustrates the data file information.

The overall methodology used in the BARD/BARN data base generation is described in Figure 1. Details of the data flow are more fully described in section 2.2, below. The data bases are available on high-density floppy disks. Requests for the data should be forwarded to the MRC-Nashua, NH office. Future updates to the data bases will be distributed to registered users.

2.2 CODE CALCULATIONS: ARCHON, NLTE, MODTRAN AND OVERLAP REGION.

2.2.1 ARCHON Chemical Dynamics Description.

The details of the ARCHON code have been described elsewhere[5] and will only be synopsized here. ARCHON is a first-principles chemical dynamics code designed to meet the needs of DNA NWE descriptions of disturbed atmospheric chemistry. It is sufficiently flexible and robust that it can be used as an ambient atmospheric chemistry descriptor. ARCHON incorporates a kinetics integration scheme which makes no steady-state assumptions, that is, it calculates the kinetic details within each time step. The reaction and rate data set used by ARCHON are in an external data file, easily accessed by the user. This set specifically describes each vibrational level of the constituents as a separate species. Using ARCHON, together with complete descriptions of the chemical and physical processes in the atmosphere, we calculate species' vibrational population distributions as a function of altitude. The kinetic rate data used for these calculations has been critically reviewed[1,2,5].

Table 1. BARD/BARN bin parametric definition.

Bin	μm	cm^{-1}	max cm^{-1}	min cm^{-1}	Δcm^{-1}	$\Delta \mu m$
1	2.000	5000.000	5125.000	4875.000	250.000	0.100
2	2.103	4756.098	4875.000	4637.195	237.805	0.105
3	2.210	4524.093	4637.195	4410.991	226.205	0.111
4	2.324	4303.406	4410.991	4195.821	215.170	0.116
5	2.443	4093.484	4195.821	3991.146	204.674	0.122
6	2.568	3893.801	3991.146	3796.456	194.690	0.128
7	2.700	3703.860	3796.456	3611.264	185.193	0.135
8	2.838	3523.184	3611.264	3435.104	176.159	0.142
9	2.984	3351.321	3435.104	3267.538	167.566	0.149
10	3.137	3187.842	3267.538	3108.146	159.392	0.157
11	3.298	3032.338	3108.146	2956.530	151.617	0.165
12	3.467	2884.419	2956.530	2812.309	144.221	0.173
13	3.645	2743.716	2812.309	2675.123	137.186	0.182
14	3.832	2609.876	2675.123	2544.629	130.494	0.192
15	4.028	2482.565	2544.629	2420.501	124.128	0.201
16	4.235	2361.464	2420.501	2302.428	118.073	0.212
17	4.452	2246.271	2302.428	2190.114	112.314	0.223
18	4.680	2136.697	2190.114	2083.280	106.835	0.234
19	4.920	2032.468	2083.280	1981.656	101.623	0.246
20	5.172	1933.323	1981.656	1884.990	96.666	0.259
21	5.438	1839.015	1884.990	1793.039	91.951	0.272
22	5.717	1749.307	1793.039	1705.574	87.465	0.286
23	6.010	1663.975	1705.574	1622.375	83.199	0.300
24	6.318	1582.805	1622.375	1543.235	79.140	0.316
25	6.642	1505.595	1543.235	1467.955	75.280	0.332
26	6.983	1432.152	1467.955	1396.348	71.608	0.349
27	7.341	1362.291	1396.348	1328.233	68.114	0.367
28	7.717	1295.837	1328.233	1263.442	64.792	0.386
29	8.113	1232.626	1263.442	1201.810	61.631	0.406
30	8.529	1172.498	1201.810	1143.185	58.625	0.426
31	8.966	1115.303	1143.185	1087.420	55.765	0.448
32	9.426	1060.898	1087.420	1034.375	53.045	0.471
33	9.909	1009.147	1034.375	983.918	50.457	0.495
34	10.418	959.920	983.918	935.922	47.996	0.521
35	10.952	913.095	935.922	890.267	45.655	0.548
36	11.513	868.554	890.267	846.840	43.428	0.576
37	12.104	826.185	846.840	805.530	41.309	0.605
38	12.725	785.883	805.530	766.236	39.294	0.636
39	13.377	747.548	766.236	728.859	37.377	0.669
40	14.063	711.082	728.859	693.305	35.554	0.703
41	14.784	676.395	693.305	659.485	33.820	0.739
42	15.542	643.400	659.485	627.315	32.170	0.777
43	16.339	612.015	627.315	596.714	30.601	0.817
44	17.177	582.160	596.714	567.606	29.108	0.859
45	18.058	553.762	567.606	539.918	27.688	0.903
46	18.984	526.750	539.918	513.581	26.337	0.949
47	19.958	501.055	513.581	488.528	25.053	0.998
48	20.981	476.613	488.528	464.698	23.831	1.049
49	22.057	453.363	464.698	442.029	22.668	1.103
50	23.189	431.248	442.029	420.467	21.562	1.159
51	24.378	410.212	420.467	399.956	20.511	1.219
52	25.628	390.201	399.956	380.446	19.510	1.281
53	26.942	371.167	380.446	361.888	18.558	1.347
54	28.324	353.061	361.888	344.235	17.653	1.416
55	29.776	335.839	344.235	327.443	16.792	1.489
56	31.303	319.457	327.443	311.470	15.973	1.565
57	32.908	303.873	311.470	296.276	15.194	1.645

Table 2. Format of BARD/BARN ASCII datafile.

KM	μm	W cm^{-2} sr^{-1}	KM	μm	W cm^{-2} sr^{-1}	KM	μm	W cm^{-2} sr^{-1}
195.00	2.000	2.410e-17	195.00	2.103	1.627e-18	195.00	32.908	4.999e-13
190.00	2.000	5.011e-17	190.00	2.103	3.328e-18	190.00	32.908	1.012e-12
185.00	2.000	8.191e-17	185.00	2.103	5.396e-18	185.00	32.908	1.634e-12
180.00	2.000	1.713e-16	180.00	2.103	1.051e-17	180.00	32.908	3.263e-12
	.	.		.	.		.	.
	.	.		.	.		.	.
	.	.		.	.		.	.
40.00	2.000	1.215e-08	40.00	2.103	7.440e-09	40.00	32.908	2.288e-06
39.00	2.000	1.494e-08	39.00	2.103	1.028e-08	39.00	32.908	2.885e-06
38.00	2.000	1.711e-08	38.00	2.103	1.179e-08	38.00	32.908	3.182e-06
37.00	2.000	1.964e-08	37.00	2.103	1.354e-08	37.00	32.908	3.505e-06
36.00	2.000	2.257e-08	36.00	2.103	1.558e-08	36.00	32.908	3.875e-06
35.00	2.000	2.596e-08	35.00	2.103	1.794e-08	35.00	32.908	4.276e-06
	.	.		.	.		.	.
	.	.		.	.		.	.
	.	.		.	.		.	.
2.00	2.000	5.456e-07	2.00	2.103	7.754e-07	2.00	32.908	8.616e-05
1.00	2.000	5.156e-07	1.00	2.103	7.228e-07	1.00	32.908	8.624e-05
0.01	2.000	4.889e-07	0.01	2.103	6.651e-07	0.01	32.908	8.632e-05

The data set contains the five major infrared *active constituents*, CO_2, CO, H_2O, O_3, and NO. We use the important[1,2] vibrational states for each emitter as a separate species. For BARD/BARN Version 4.1, there are 19 vibrational quantum states for CO_2, 3 vibrational quantum states each for NO and CO, 8 vibrational quantum states for H_2O, and 17 vibrational quantum states for O_3.

ARCHON uses a complete description of the kinetic processes for each infrared emitter. There are a variety of sources for the kinetic data. A compilation by Archer[2] was used for the CO_2 physical kinetic description. The hydroxyl/ozone chemical kinetic system uses a combination of Rawlins[9] and CODATA[3] compilations. For the species CO, NO and H_2O, the compilation from the DELTA[1] code was used.

In order to calculate the proper ozone concentrations, the associated hydroxyl/water chemistry[3] was included. Ozone is known to be produced by chemiluminescent[9] reactions under these conditions and is characterized by the 17 vibrational states used. While the vibrational state concentrations of hydroxyl are calculated, its contribution to the radiance is not yet included in BARD/BARN Version 4.1. Hydroxyl is produced by chemiluminescent mechanisms with up to 9 vibrational quanta. Solar pumping will populate all 12 vibrational levels, and all these states radiate, with varying strengths, from 1 μm to 16 μm. Later revisions of BARD/BARN will include the hydroxyl emission.

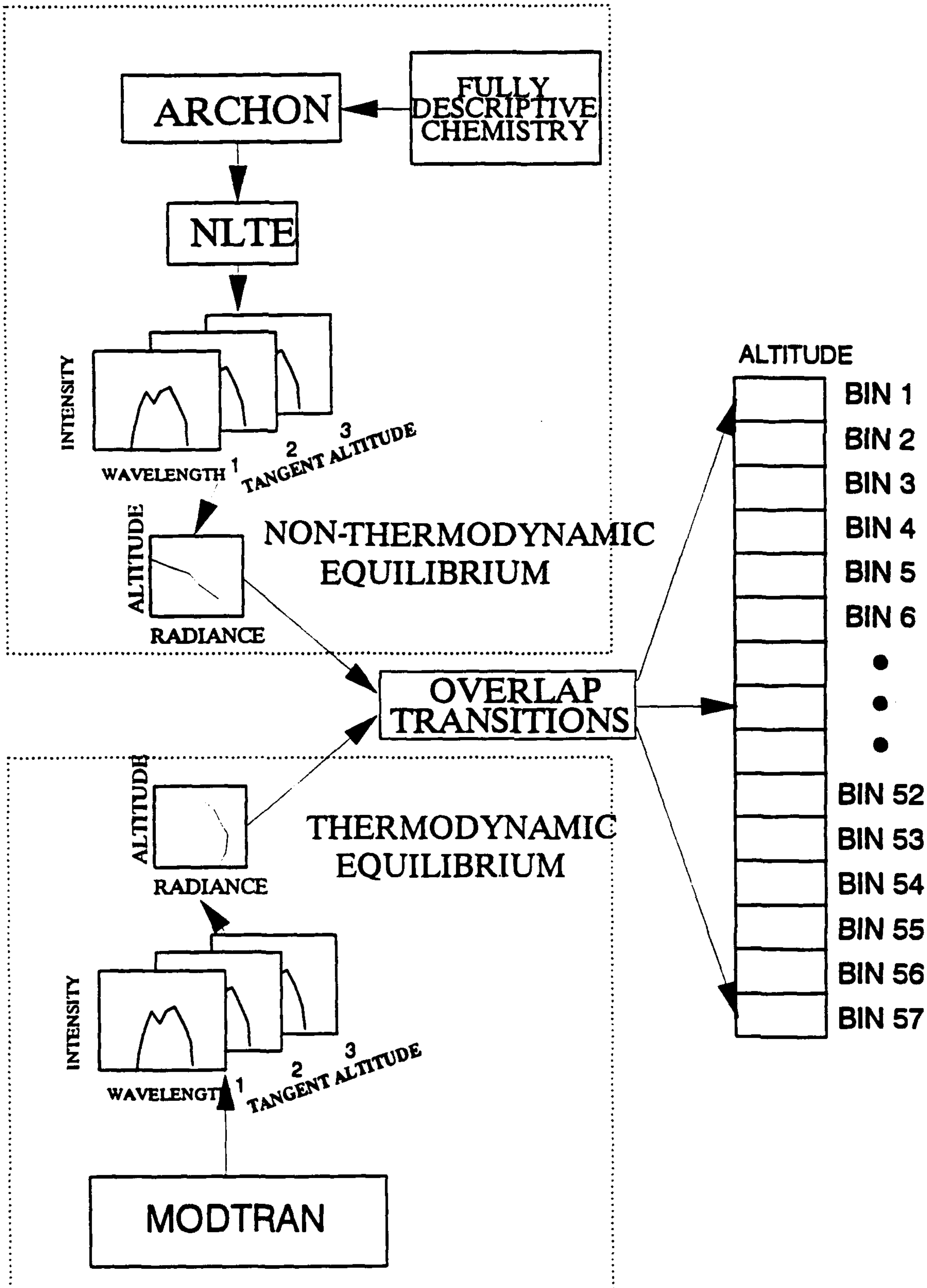

Figure 1. Schematic of BARD/BARN methodology.

Version 4.1 of BARD/BARN currently includes only the major isotope of CO_2. It is known that the minor isotopes of CO_2 contribute to the radiance and provide an important mechanism for trapped photons to ultimately escape. The 636 isotope, because its band centers are slightly red-shifted compared to the corresponding 626 isotope, is optically thin at lower altitudes. Future revisions of BARD/BARN will include the important isotopes.

The kinetic system uses 63 vibrational levels among the species plus the surrounding 'spectator' species, such as O, O_2, and N_2 that influence the emitting species population distributions. There is a total of 78 levels in the kinetic calculations. The species concentrations are defined at 25 altitudes for sub-arctic day and night conditions. We start at 40 km and end at 200 km. The altitudes between 40 km and 100 km are more densely sampled since the transitions from local thermal distributions to non-local thermal distributions take place in this region. The altitudes above 100 km are sampled at 10 km intervals. For altitudes above 100 km, the radiance values begin to scale with the exponential lapse rate of the atmospheric constituents. The calculation ends at 200 km since the radiance originating from the atmosphere falls below the background zodiacal emission at about this altitude.

2.2.2 Local Radiation Field.

A key problem related to a complete and accurate description of the physical/chemical processes is the treatment of the local radiation field, ρB. In general there are two approaches to this difficult problem.

One approach is to use a Monte Carlo statistical treatment of the photon scattering/escape processes. The Monte Carlo method closely models the physics that govern the scattering/escape processes. The Phillips Laboratory code, SHARC[11], uses the Monte Carlo procedure to calculate the local radiation field. For on-line earthlimb line-of-sight code calculations, this approach, while computationally intensive, is a robust and more 'exact' approach.

Another approach, used for BARD/BARN, is based on a phenomenological model developed by Kumer and James[7]. The Kumer and James model relies on parametric descriptions of column density of absorbing molecules between the radiation source (i.e. earth or sun) and the absorption cross section of the molecular transition. The column density of molecules between the radiating source and the local cell determines the attenuation of the excitation radiation. The scattering/escape processes are divided into band transport functions.

The first transport function is W_b. Given a flux of photons incident at the top of the atmosphere, W_b describes the atmospheric attenuation to the altitude of interest (i.e how

many photons make it through). This is the transmission factor for sunshine through a column concentration, $N(cm^{-2})$. For a transition with a cross section, $\sigma(cm^2)$, the product σN is the independent variable. Therefore, using the excitation rate at the top of the atmosphere, multiplied by W_b, a function of σN, one determines the solar pumping rate for a transition taking place within the atmosphere.

The second transport function is the escape factor, T_b which determines the probability that a photon emitted in the atmosphere will not be re-absorbed after travelling through a column $N(cm^{-2})$ (i.e. how many photons make it out). If a photon is emitted in an optically thin band (i.e. σ and/or N are small) the probability of escape to space is high. As with W_b, σN is the independent variable. A low escape probability is usually associated with lower altitudes (high N) and intense transitions (large σ). The spontaneous emission rate (Einstein A coefficient) for a molecule within an atmosphere is decreased by the factor T_b.

The final transport function, Φ_b, measures the probability that a photon emitted within the atmosphere will be re-absorbed elsewhere in the atmosphere. Physically this quantity measures the amount of attenuation experienced by photons up-welling from the earth's surface. As with W_b and T_b, Φ_b is a function of σN. The rate of earthshine excitation is determined by the product of Φ_b and the unattenuated earthshine pumping rate.

These three transport functions have been tabulated by Kumer and James. For use within DELTA, Archer[1] has fit the tabular values to analytical functional forms to simplify their use. We use the DELTA approach for the BARD/BARN data bases. A complete discussion of the these functions and their use is found in the documentation for DELTA.

2.2.3 Radiation Transport: NLTE and MODTRAN.

Once the data base describing the physical/chemical kinetics is fixed, ARCHON calculates the final steady state quantum state distributions for each of the 25 vertically distributed air parcels. At this point the Phillips Laboratory code, NLTE[12], is used to calculate the line-of-sight radiation transport for the non-equilibrium atmosphere described by ARCHON output. NLTE is a general-purpose line-by-line radiation transport code designed to yield radiance from arbitrary sight paths in the upper atmosphere. NLTE accesses the HiTRAN line-file[10] for spectroscopic parametric definition. It operates on the vibrational population input supplied by ARCHON (or other atmospheric chemistry code), given other parametric input information including kinetic temperature, total constituent concentrations and spectral definition of output requirements. The only limiting assumption within NLTE is that spectroscopic lines do not overlap. Thus the output is normally limited by the user to altitudes where pressure-broadening is not significant. This is a function of the line congestion, but generally occurs around 40-50 km. Increasing error is introduced below this altitude region, but other codes, such as MODTRAN (below) are generally applicable in the lower-altitude boundary region of NLTE.

NLTE was run for each individual transition contribution within each wavelength bin. There were 75 infrared transitions used to calculate the BARD/BARN data bases. Most of the transitions overlapped several bins. Consequently, there were about a thousand NLTE calculations to fill all the bins with the appropriate transitions. With NLTE, this was easily accomplished in batch mode.

For the thermodynamic equilibrium region of the atmosphere, the line-of-sight radiance contribution was calculated with the Phillips Laboratory code MODTRAN[4]. MODTRAN, a derivative of LOWTRAN 7[6], is a band-model approach to describe the atmospheric transmittance and/or radiance from the ultraviolet to the infrared under lower-altitude LTE conditions. The output resolution of MODTRAN is 2 cm^{-1}. The code does not specifically treat atmopsheric chemistry to generate vibrational populations. It assumes a Boltzmann distribution to describe the vibrational populations. The code treates all major constituents of the lower atmosphere. MODTRAN, like NLTE, accesses the HiTRAN line file for spectroscopic parameter definition of the constituents. MODTRAN includes aerosol solar-scattering and haze models, as in LOWTRAN 7.

2.2.4 Earthlimb LTE/NLTE Radiance Profile Merging - LTE/NLTE.

The transition from LTE to NLTE does not occur at a fixed altitude. There is generally an altitude range across which the "temperature" describing molecular vibrational distributions begins to deviate from the local kinetic temperature. The altitude range across which this transition occurs is a function of the details of the chemical dynamics giving rise to the radiance in the spectral band of interest. Thus the transition is both wavelength and time-of-day dependent. This complicates the treatment of the LTE/NLTE transition region.

Fortunately, for most infrared spectral descriptions, the results of ARCHON/NLTE, calculating downward, and MODTRAN, calculating upward, agree in the LTE/NLTE transition region to within about a factor of 2 or better. Thus, for this version, we have used a log-linear interpolation across the transition region 40 - 70 km. The exception is the 2.7 μm day data, wherein there is a strong high-altitude component from the solar pumping of CO_2 combination bands. For this case we have co-added the LTE/NLTE contributions. In general, a more robust treatment will be necessary to make the transition "smart". This is especially true in the SWIR day data, where solar effects can have a pronounced effect on the NLTE radiance. Therefore, a weighted "spline" will be developed for future releases to account for detailed band-dependent deviations of the ratio of the vibrational temperature to the kinetic temperature, T_{vib}/T_{kin}.

For data-base applications, a continuous first-derivative is a necessity. We have achieved this using an analytic smoothing function for the final data set. For most bins, the transition region is moderately computationally accurate (factor of 2) and continuous in the

first derivative. This accuracy is generally better than the uncertainty associated with the atmospheric input conditions.

2.2.5 Comparisons with Experimental Data.

Given the complexity of the calculation and the requirement that the data be an accurate representation of the "real" atmospheric radiance, we have compared the BARD/BARN data to experimental data. The primary experimental data set comes from the SPIRE rocket experiment[8] . Figure 2 compares the BARD/BARN data to SPIRE data in the MWIR. Given the uncertainties in both the data and the calculation, the comparison is excellent and lends confidence to the approach leading to the BARD/BARN data base.

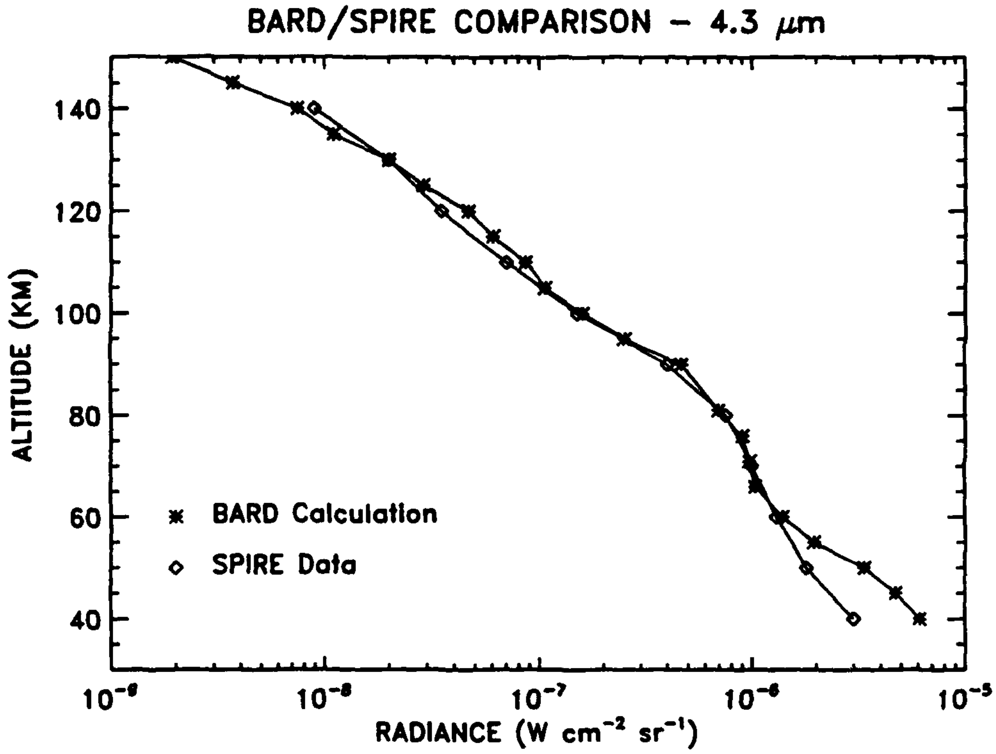

Figure 2. Comparison of BARD to SPIRE.

SECTION 3
SUMMARY OF BARD/BARN

We have graphically represented the entire BARD/BARN data set in the final section of this report. These plots show the general behavior of the radiance character that is expected. The SWIR radiance profiles show a large diurnal variation, as expected. The LWIR bins display virtually no diurnal variation, again, as expected.

Future releases of BARD/BARN will contain similar plots for upgrade comparisons.

SECTION 4
LIST OF REFERENCES

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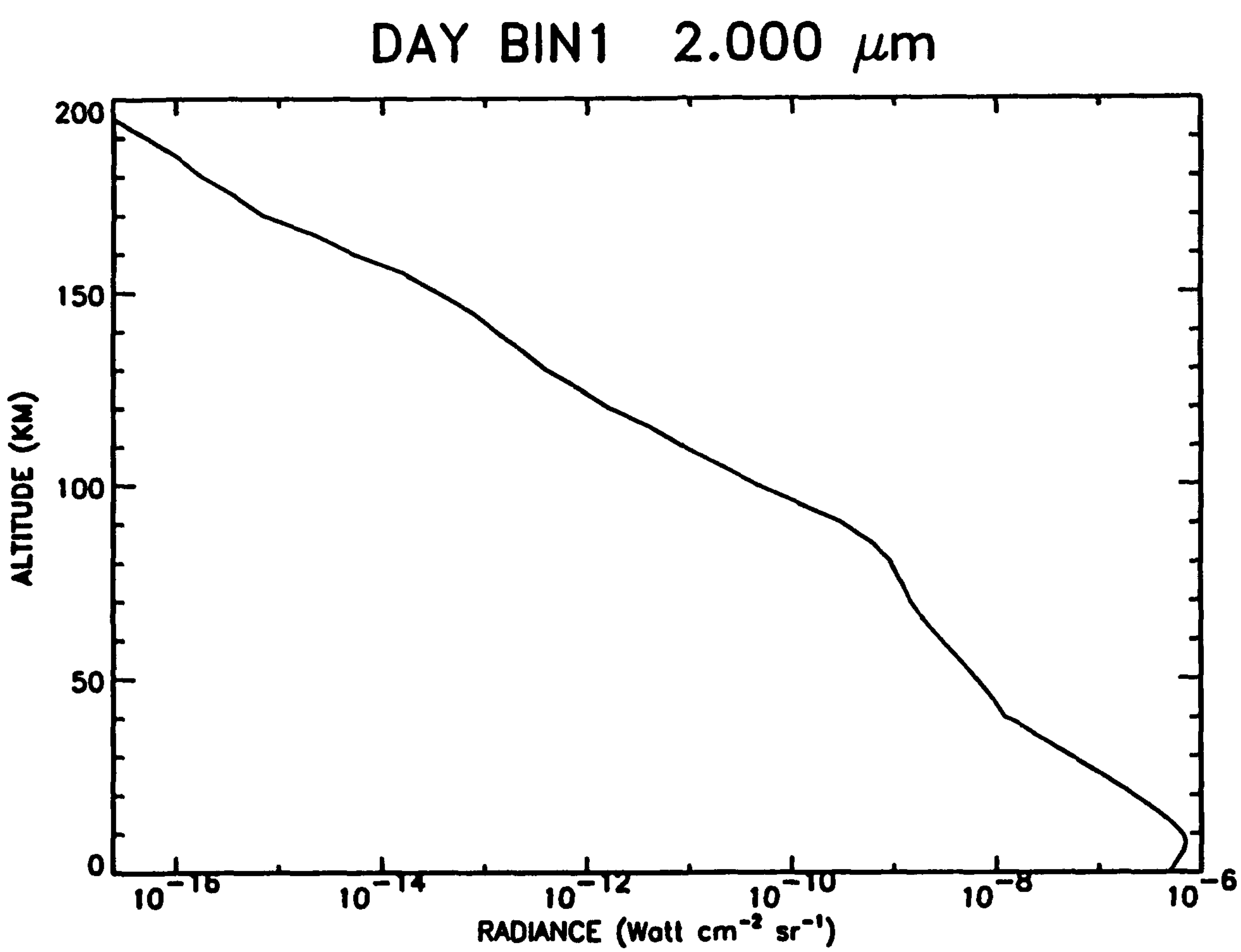
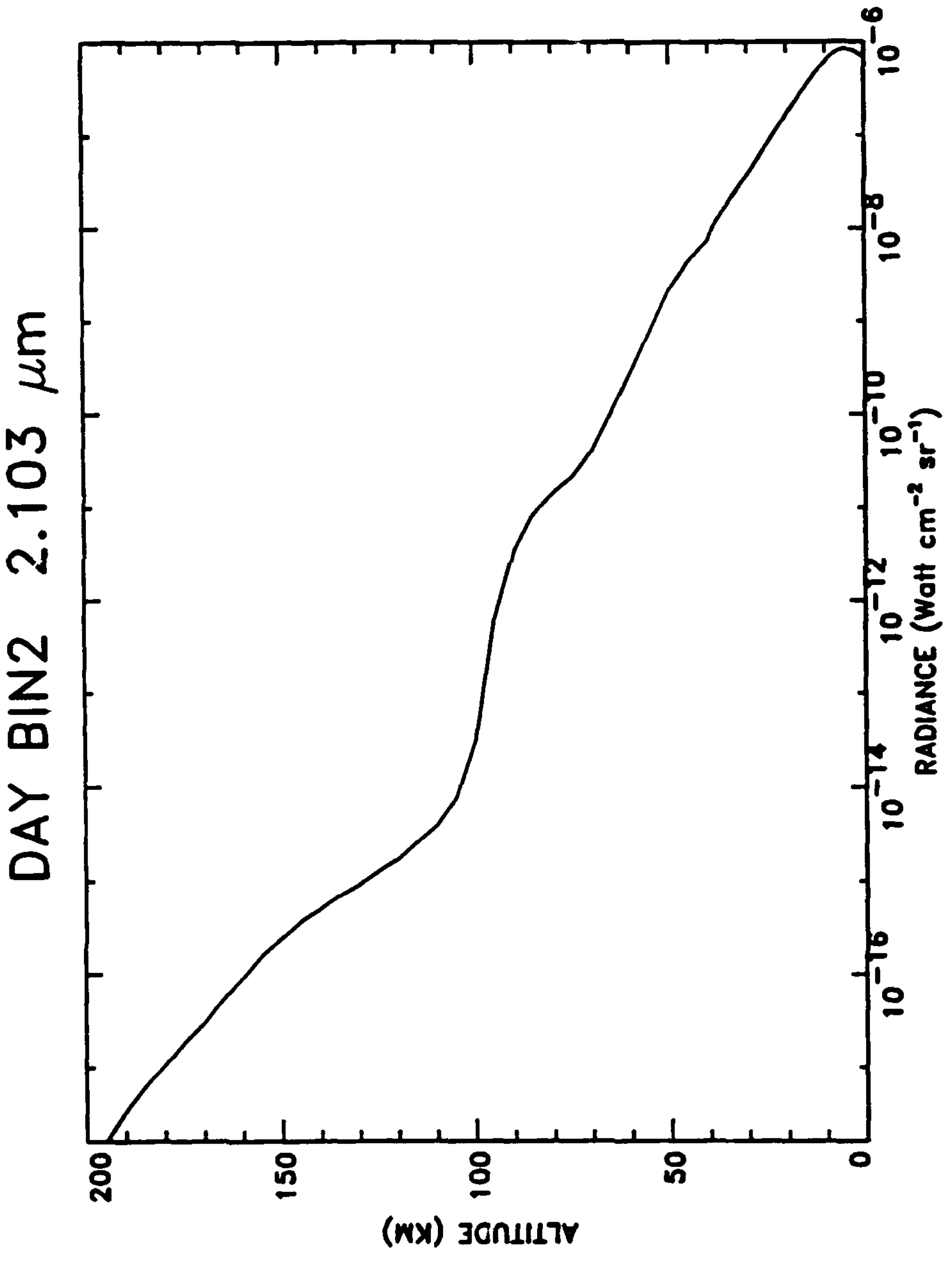
APPENDIX

BARD v4.1 Background Atmospheric Radiance Day

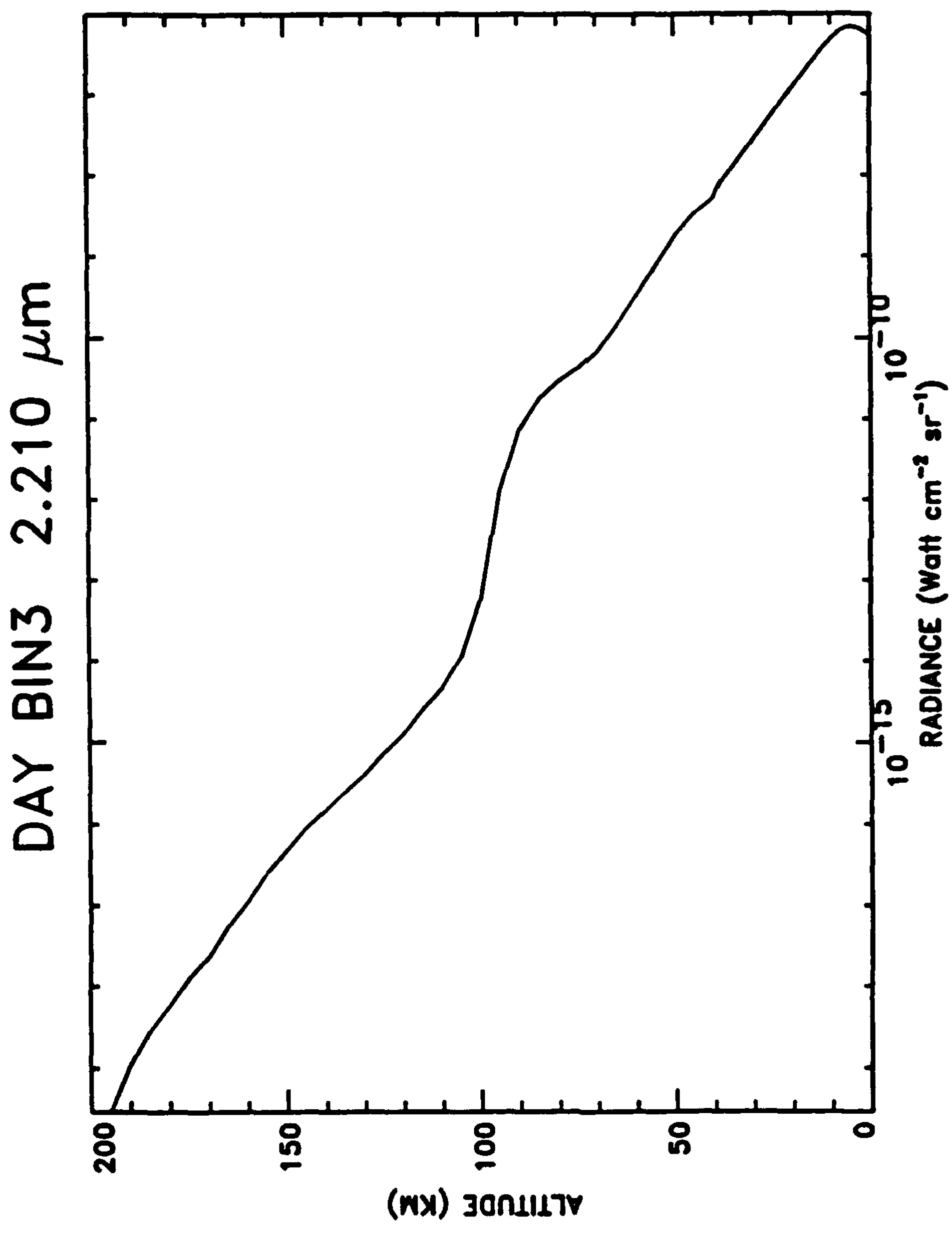
BARN v4.1 Background Atmospheric Radiance Night

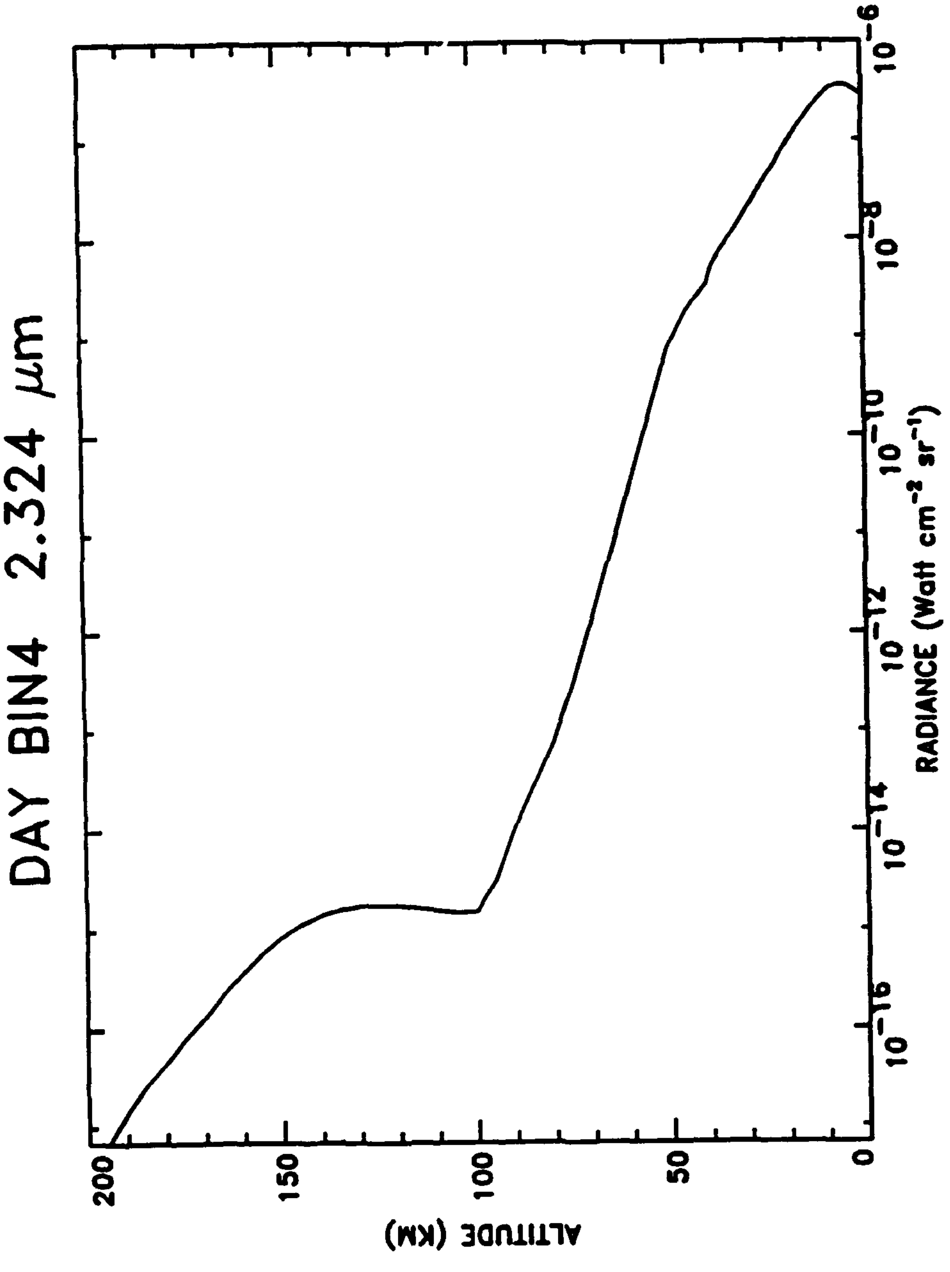


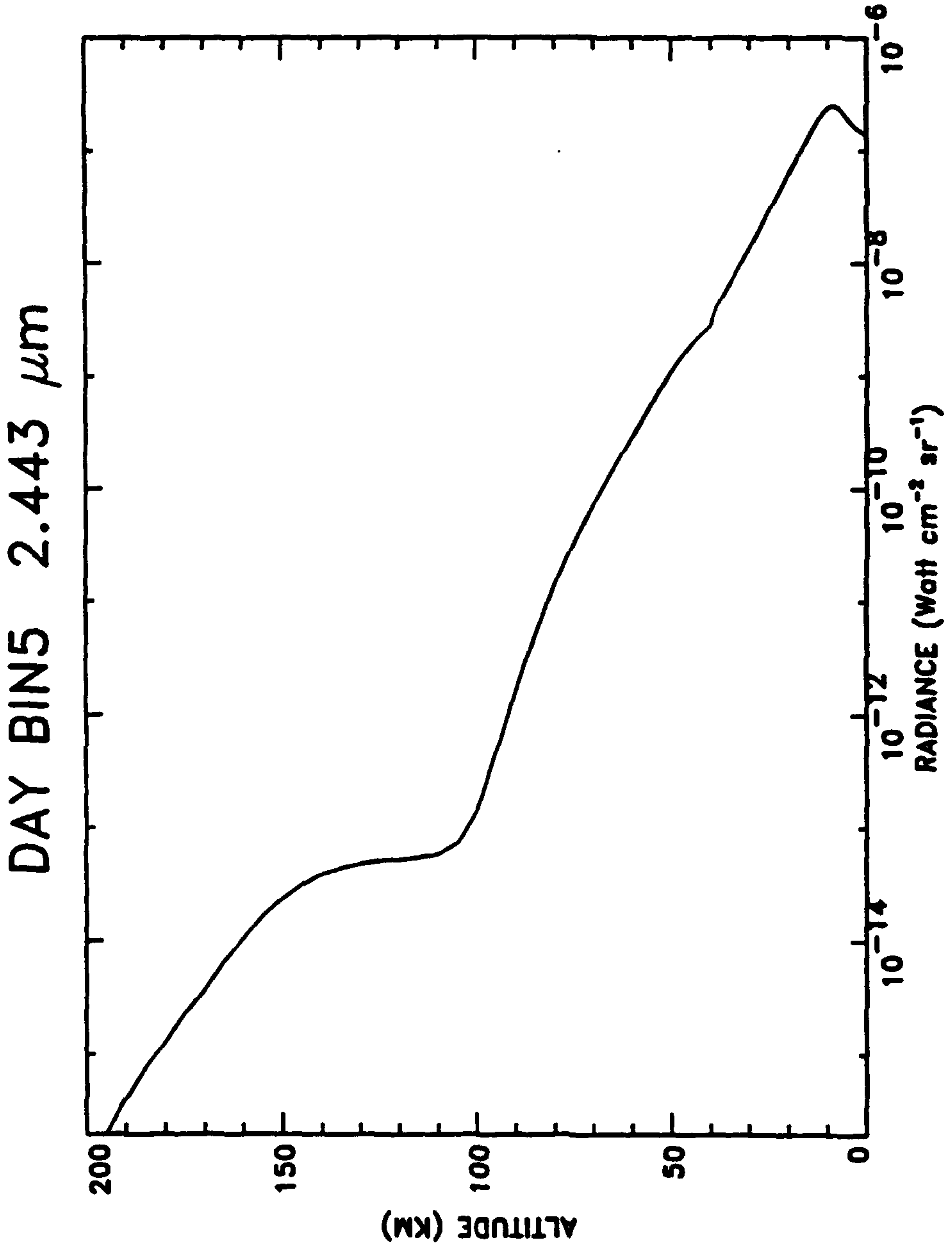
DAY BIN1 2.000 μm
ALTITUDE (KM)
200
150
100
50
0
10⁻¹⁶
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
RADIANCE (Watt cm⁻² sr⁻¹)



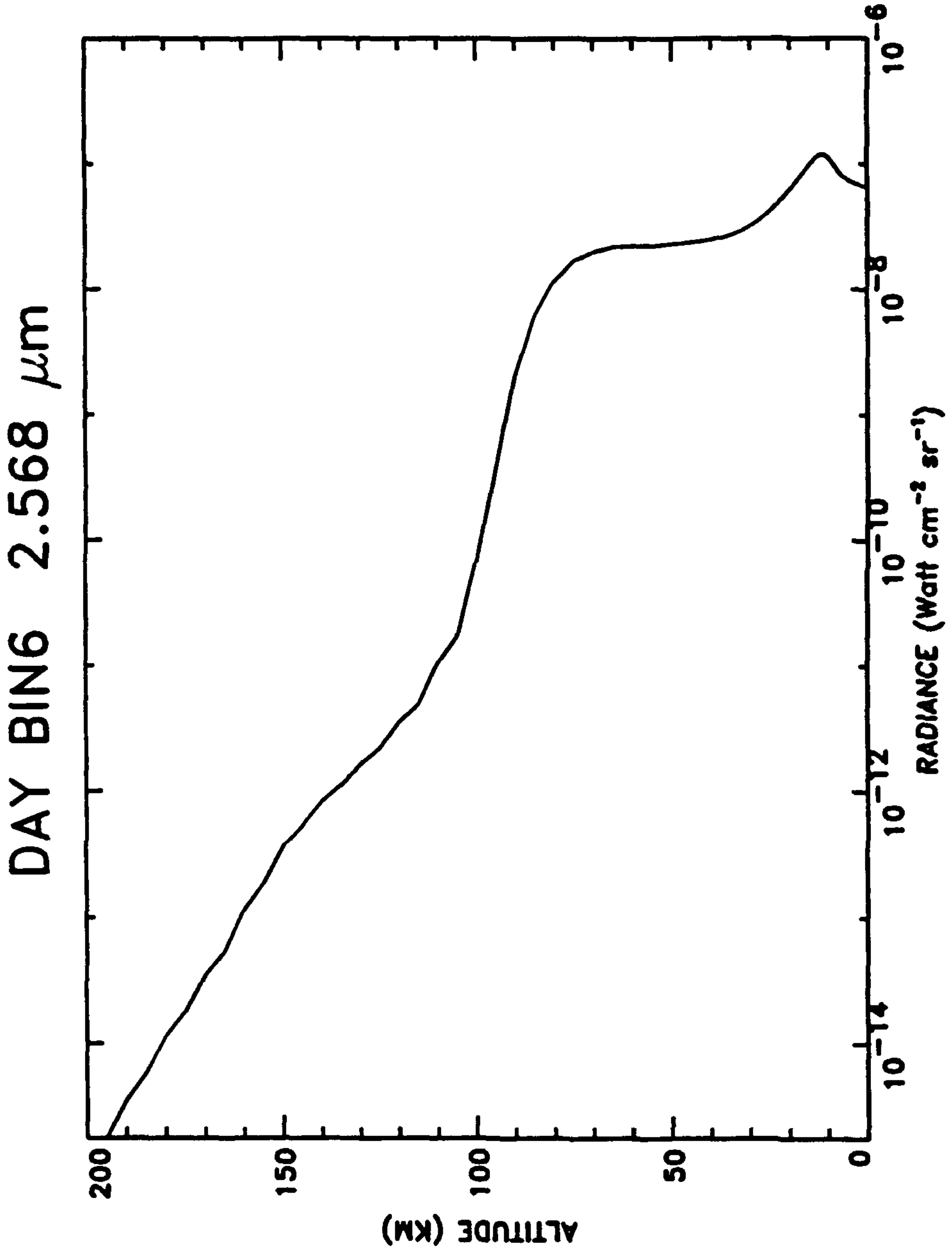
DAY BIN2 2.103 μm
ALTITUDE (KM)
200
150
100
50
0
10^-16
10^-14
10^-12
10^-10
10^-8
10^-6
RADIANCE (Watt cm^-2 sr^-1)

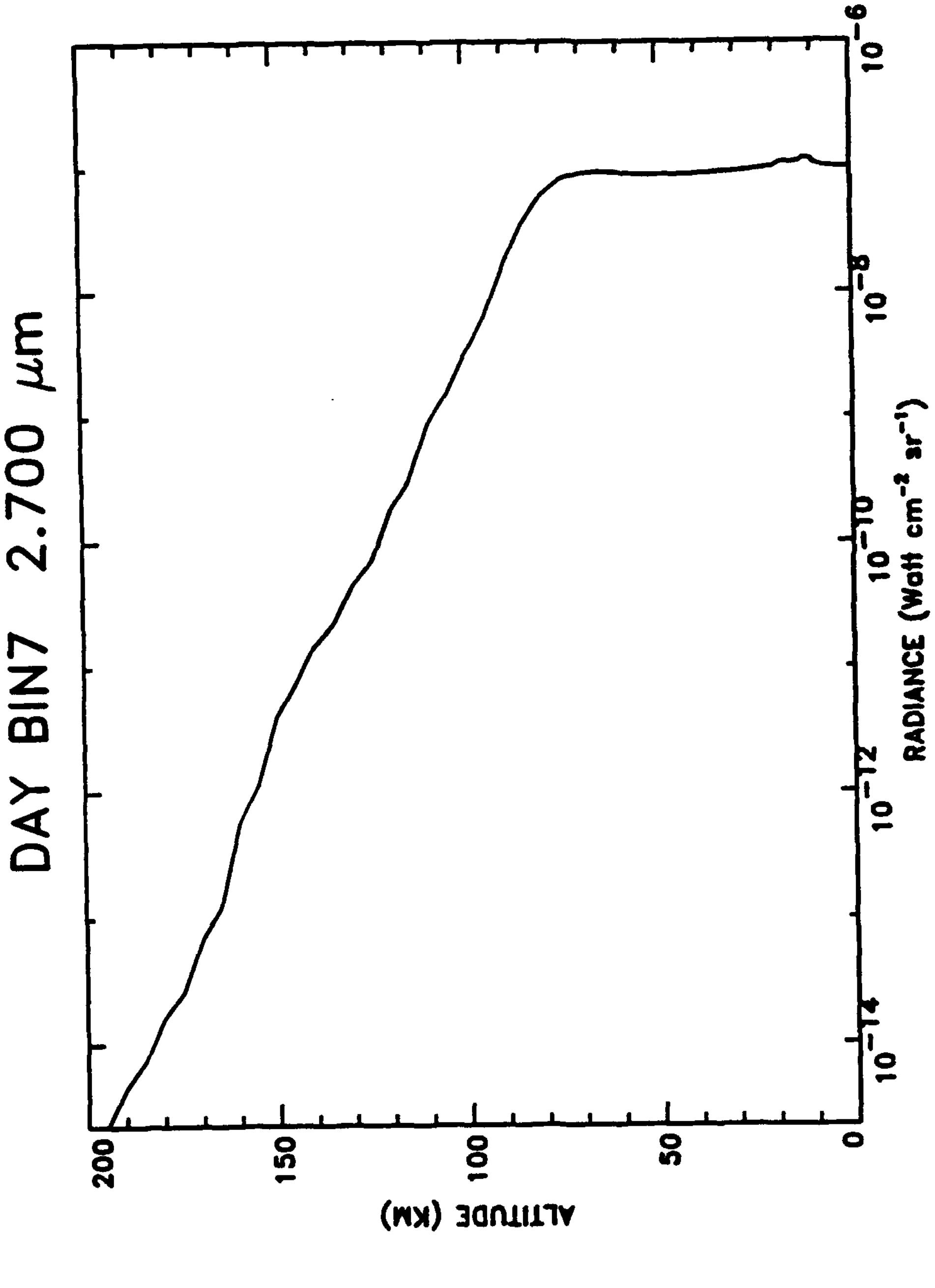

DAY BIN3 2.210 μm
ALTITUDE (KM)
200
150
100
50
0
10^-15
10^-10
RADIANCE (Watt cm^-2 sr^-1)

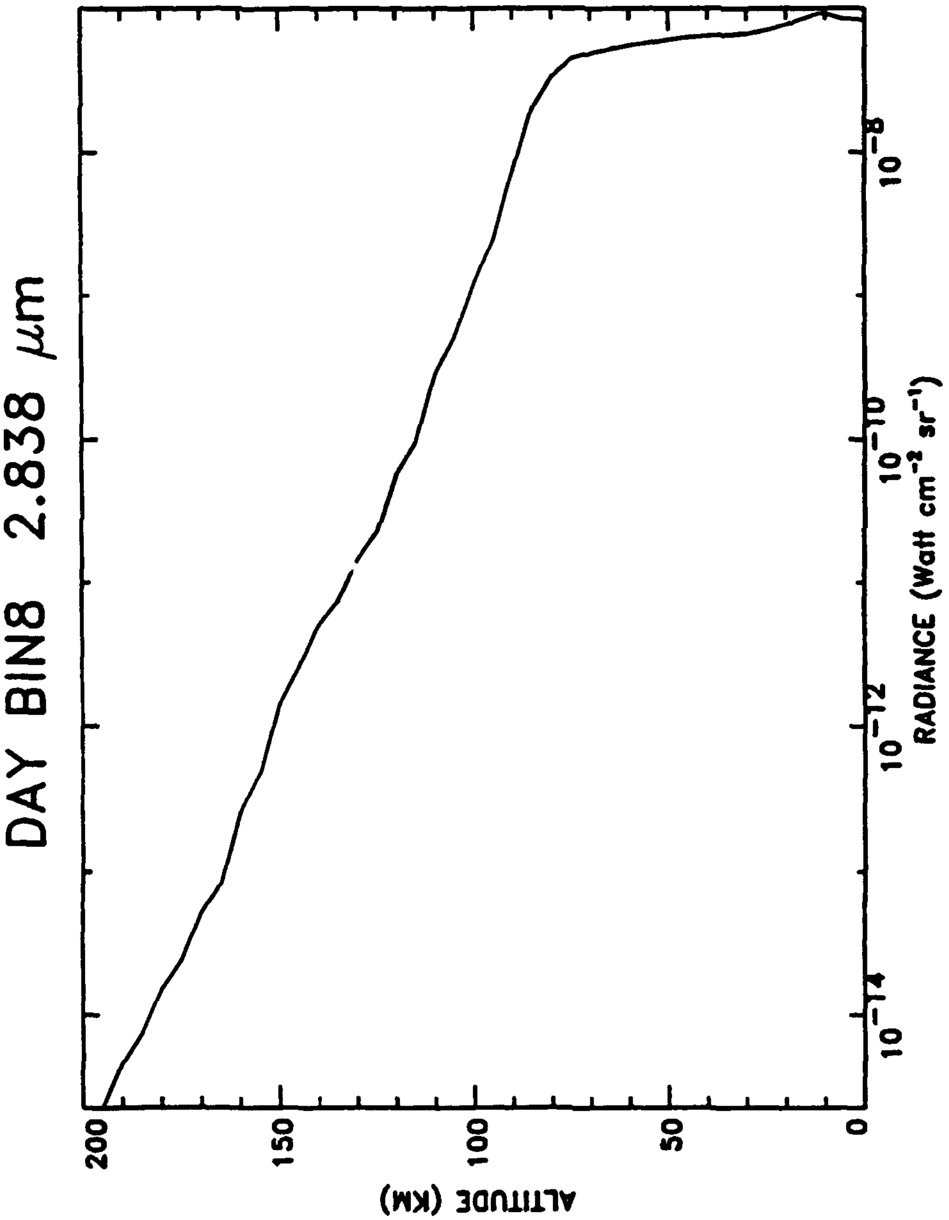

DAY BIN4 2.324 μm
ALTITUDE (KM)
RADIANCE (Watt cm⁻² sr⁻¹)
200
150
100
50
0
10^-16
10^-14
10^-12
10^-10
10^-8
10^-6



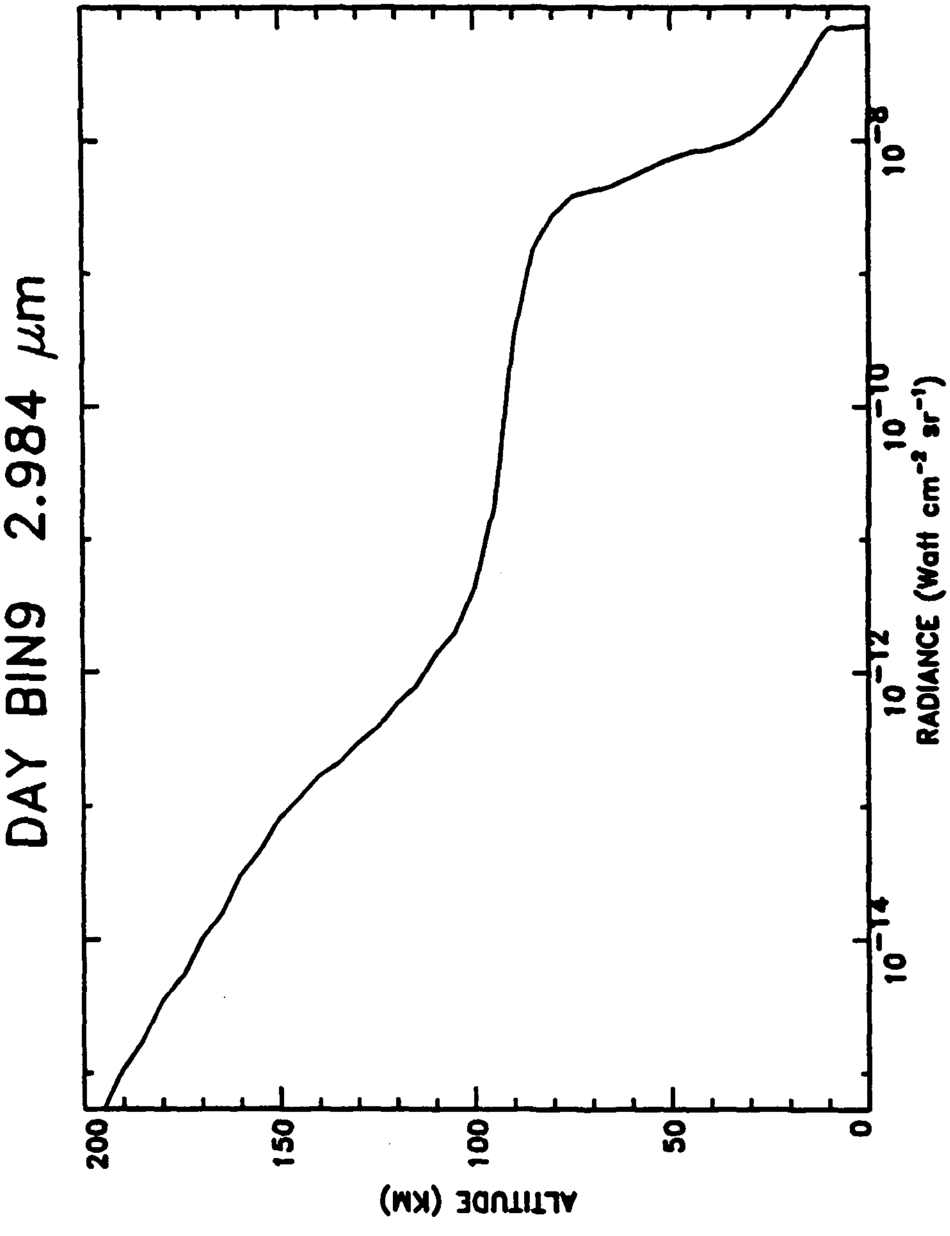
DAY BIN5 2.443 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶


DAY BIN6 2.568 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶

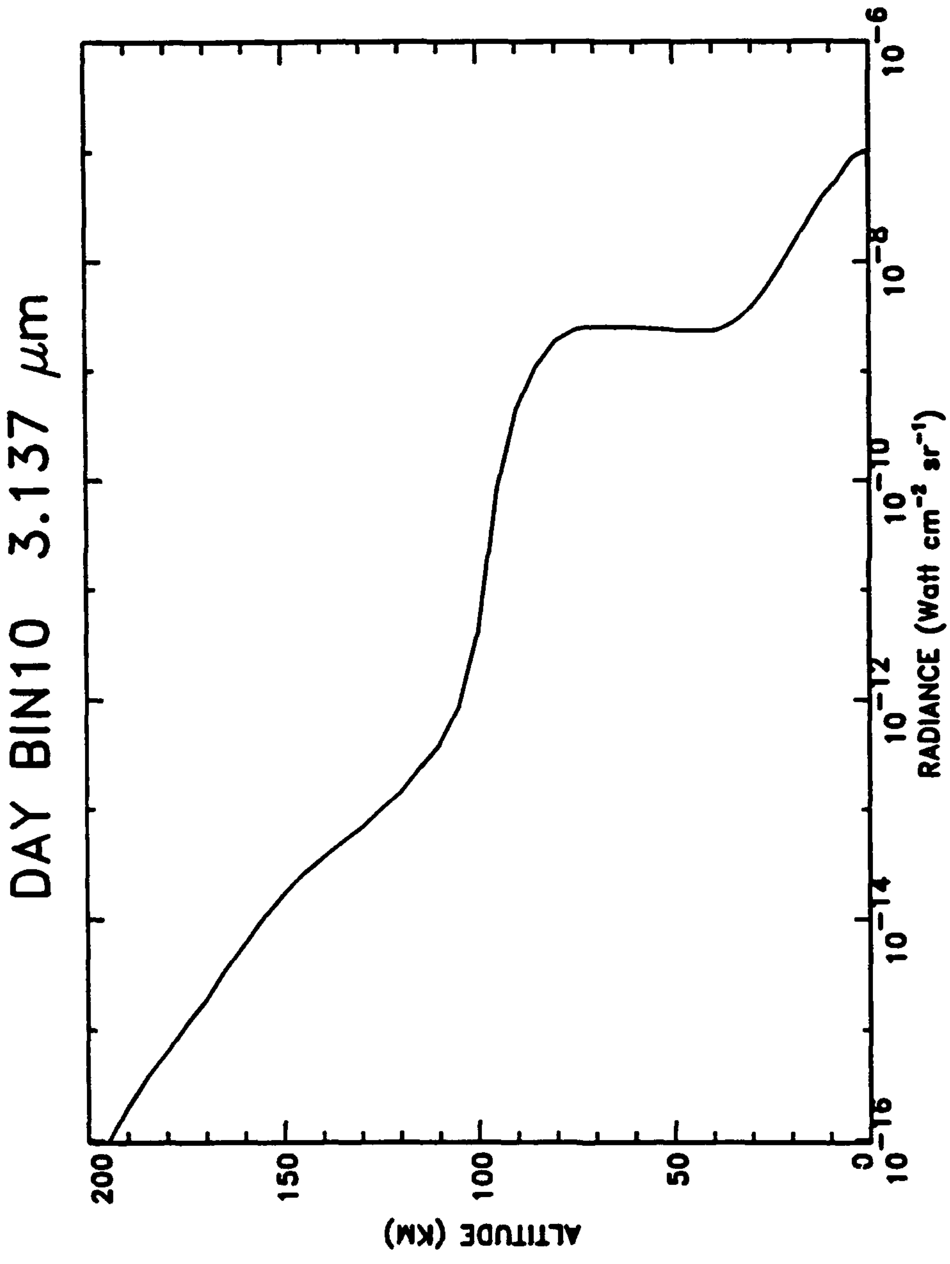

DAY BIN7 2.700 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}

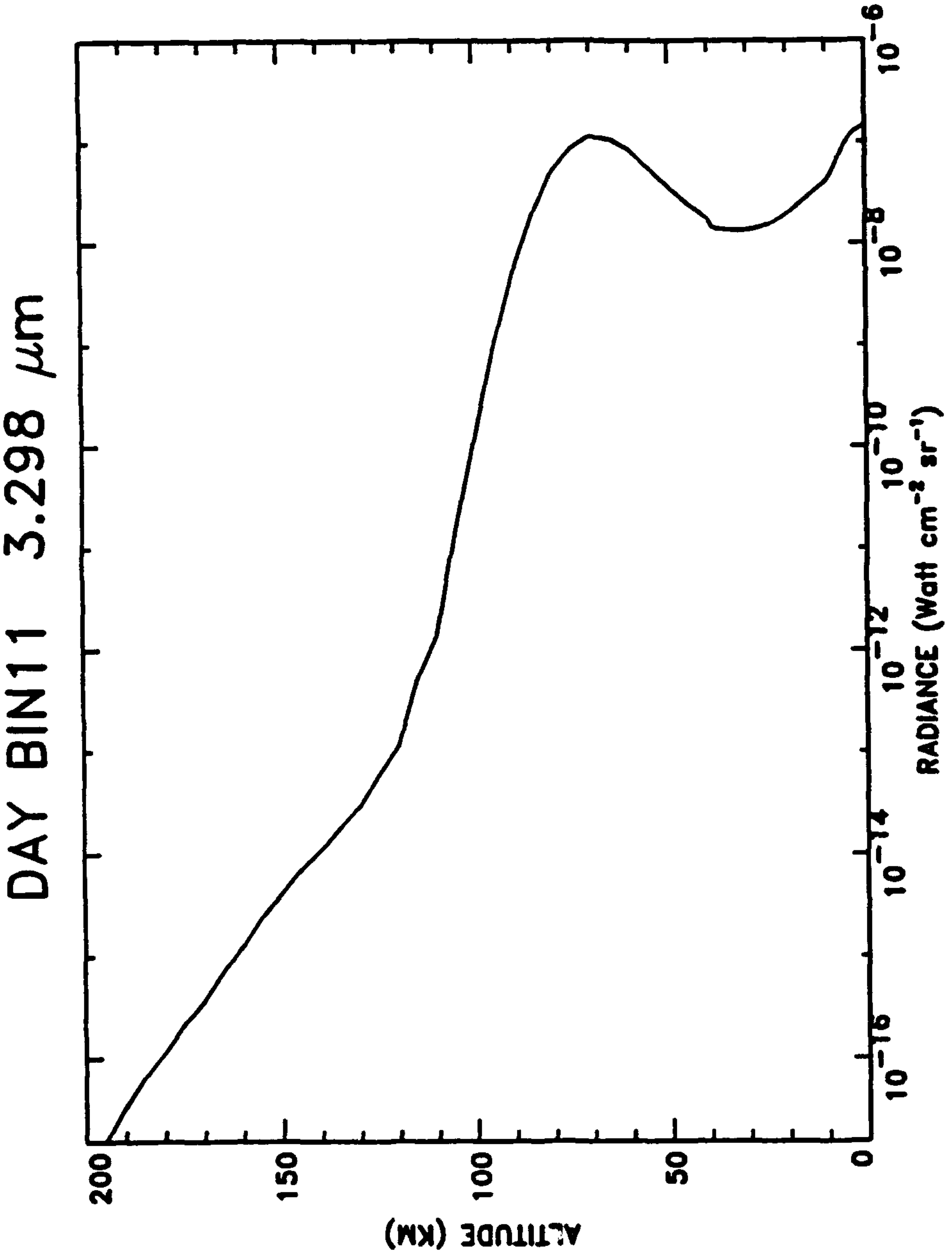


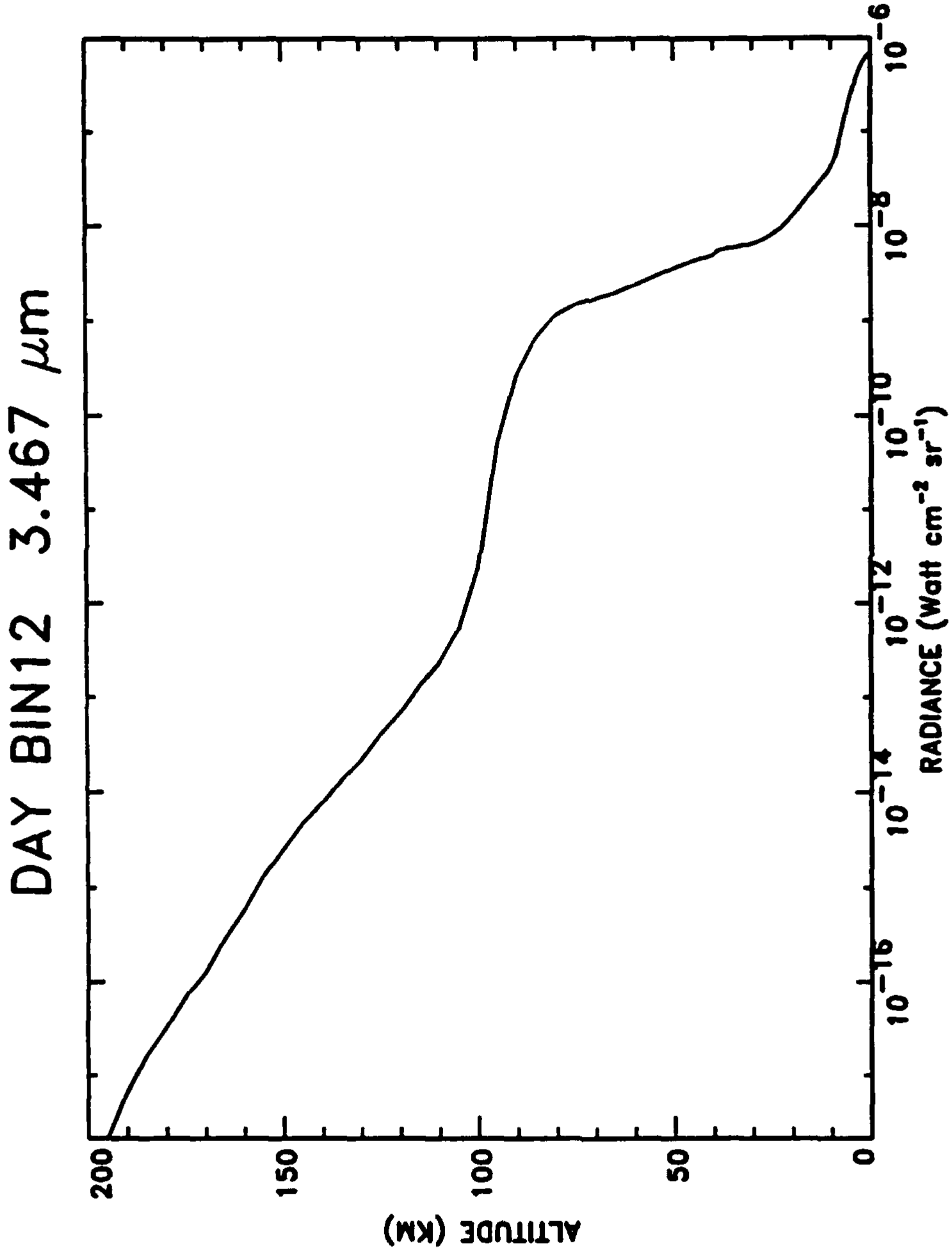
DAY BIN8 2.838 μm
ALTITUDE (KM)
200
150
100
50
0
10^-14
10^-12
10^-10
10^-8
RADIANCE (Watt cm^-2 sr^-1)



DAY BIN9 2.984 μm
ALTITUDE (KM)
200
150
100
50
0
10^-14
10^-12
10^-10
10^-8
RADIANCE (Watt cm^-2 sr^-1)

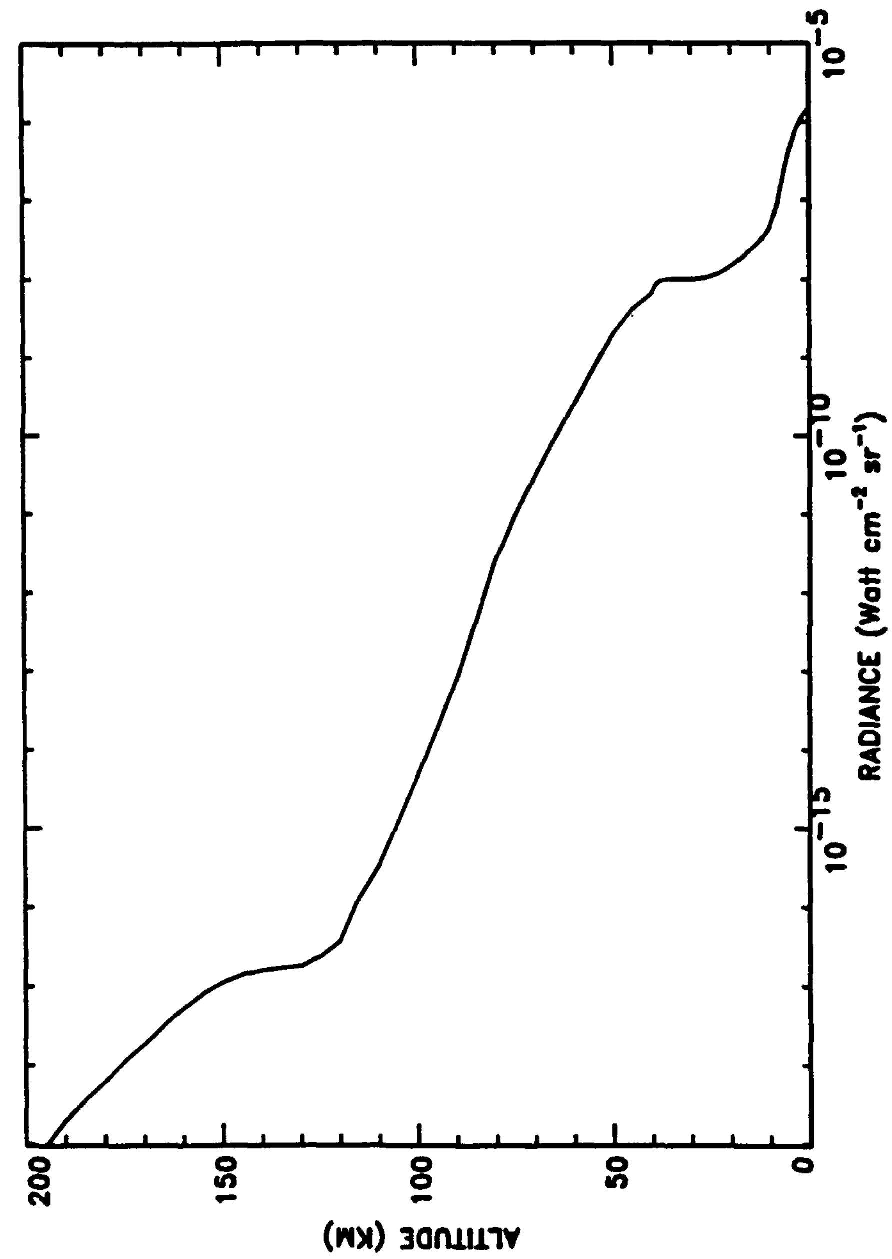

DAY BIN10 3.137 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁶
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶


DAY BIN11 3.298 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁶
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶

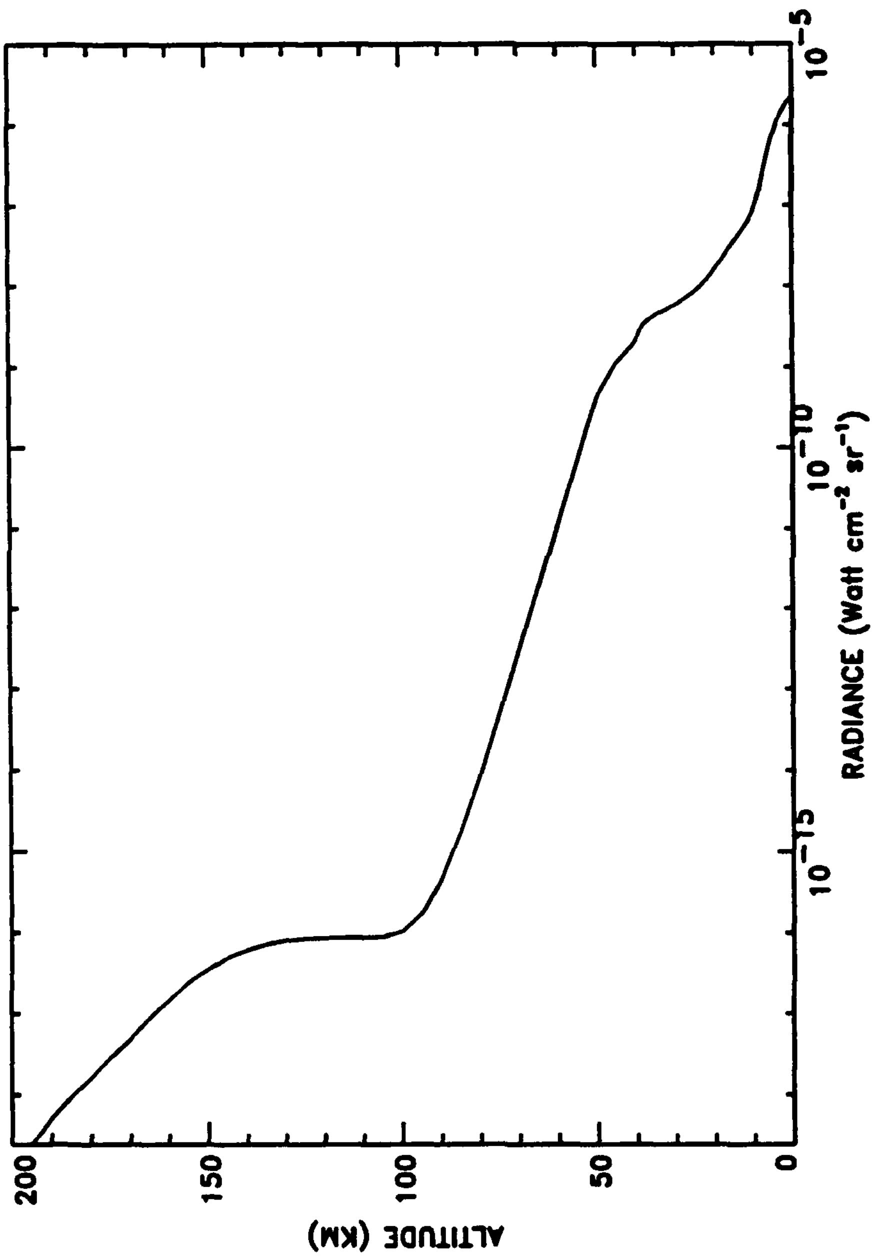


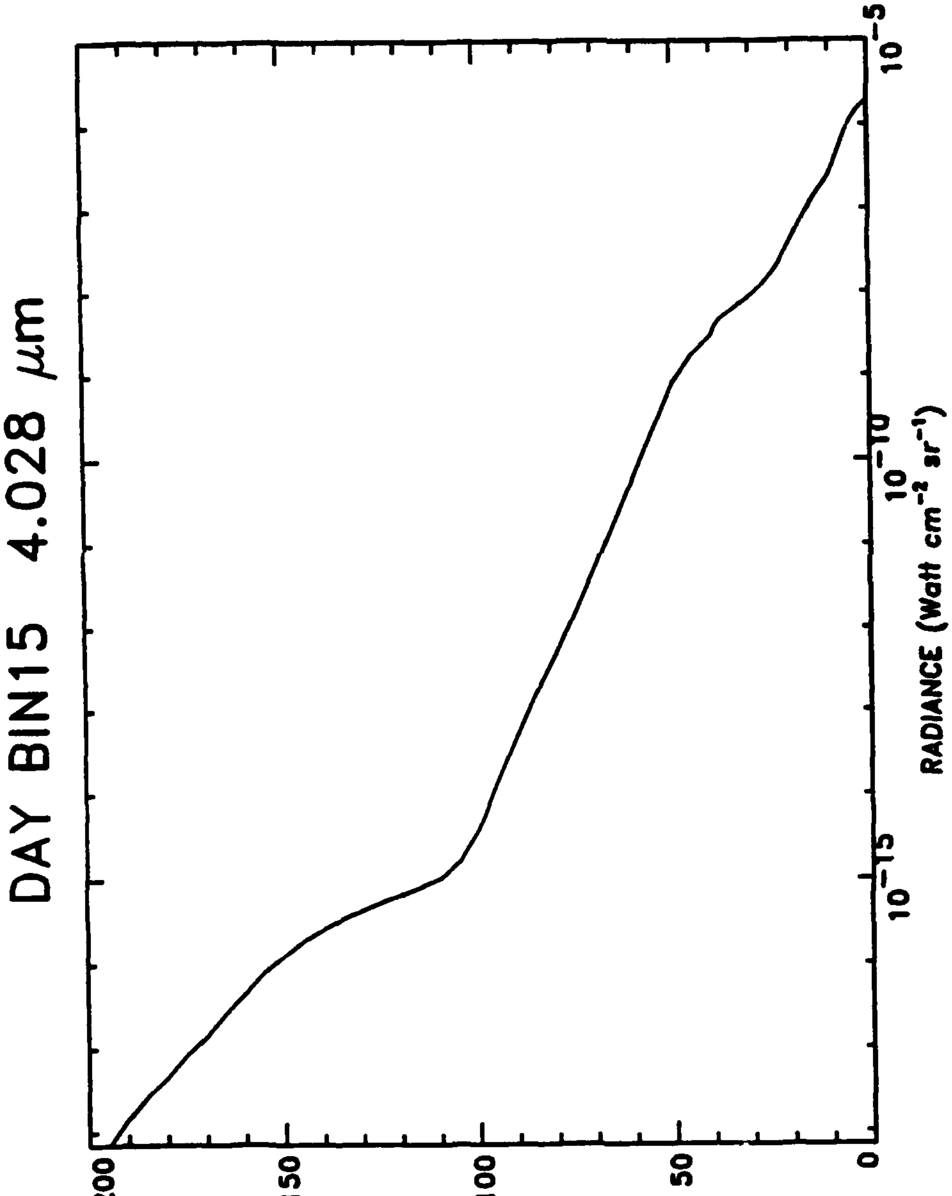
DAY BIN12 3.467 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-16}
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}

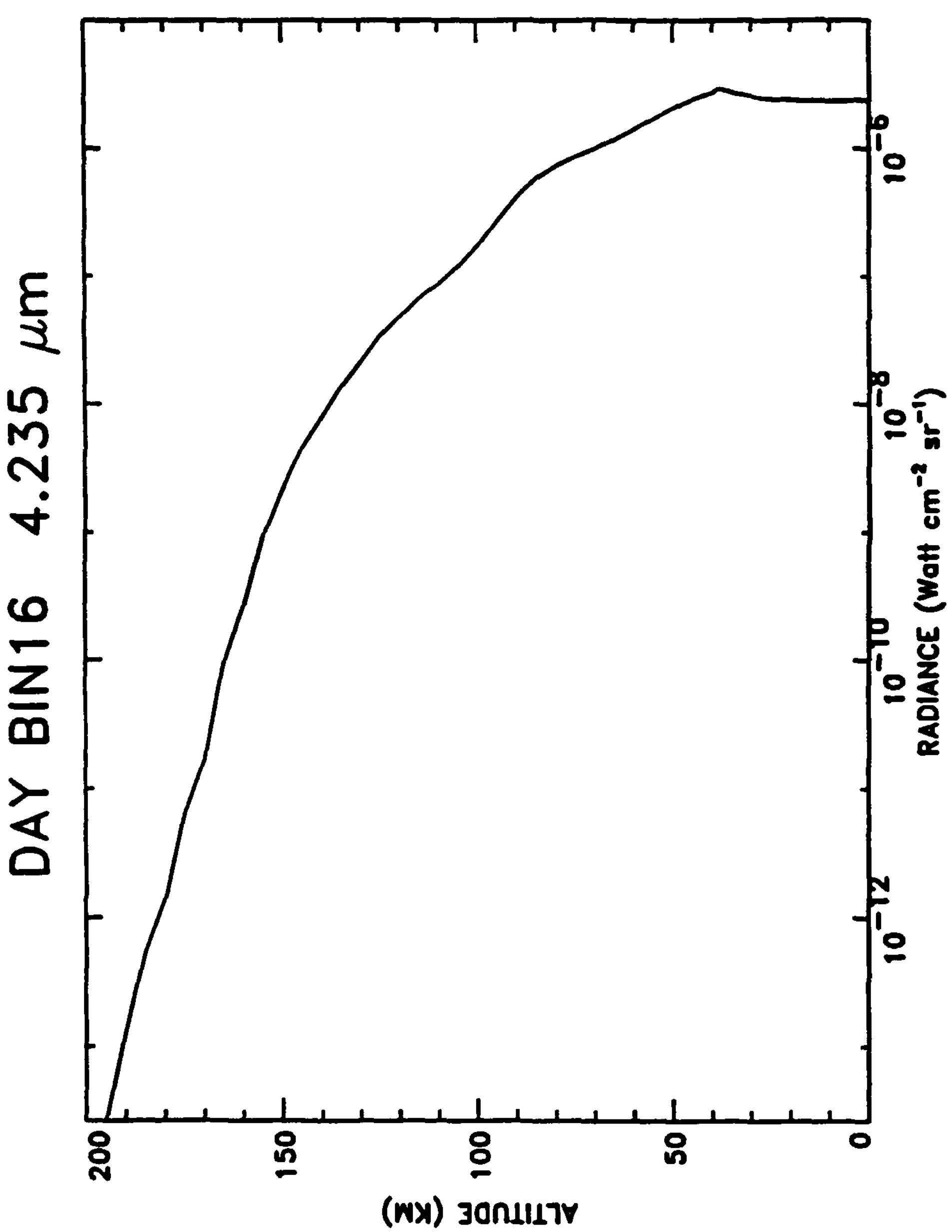
DAY BIN13 3.645 μm

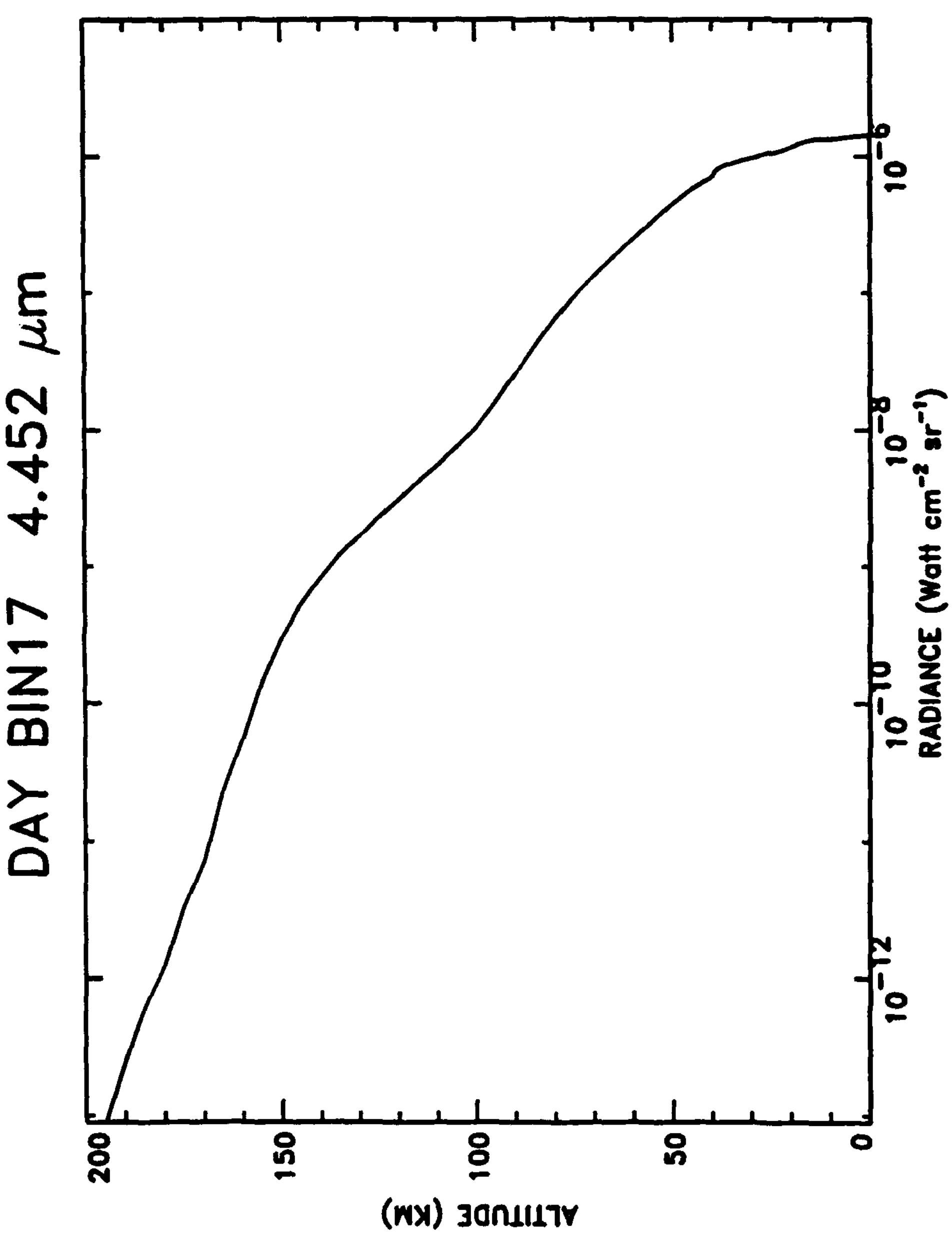


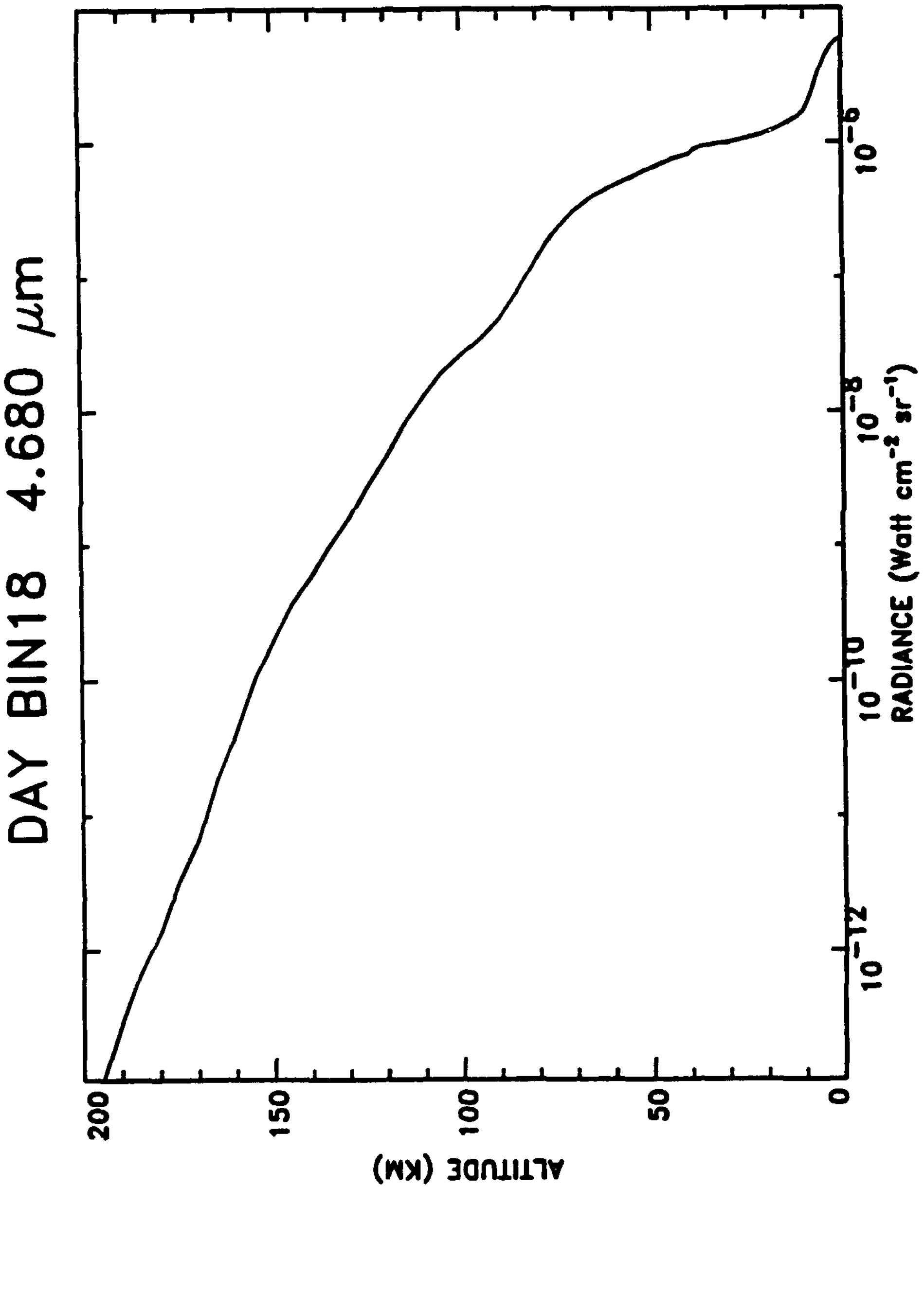
DAY BIN14 3.832 μm



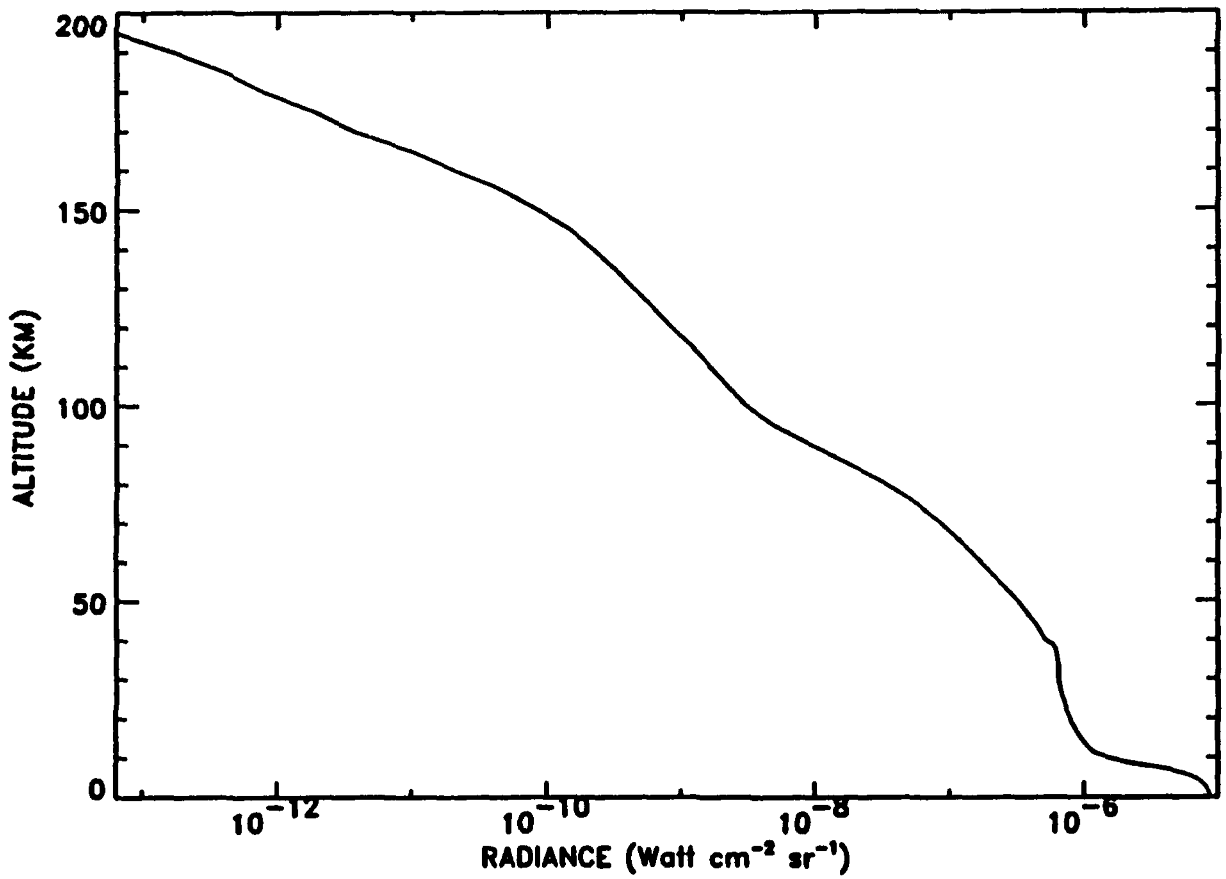

DAY BIN15 4.028 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁵
10⁻¹⁰
10⁻⁵


DAY BIN16 4.235 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^-2 sr^-1)
10^-12
10^-10
10^-8
10^-6

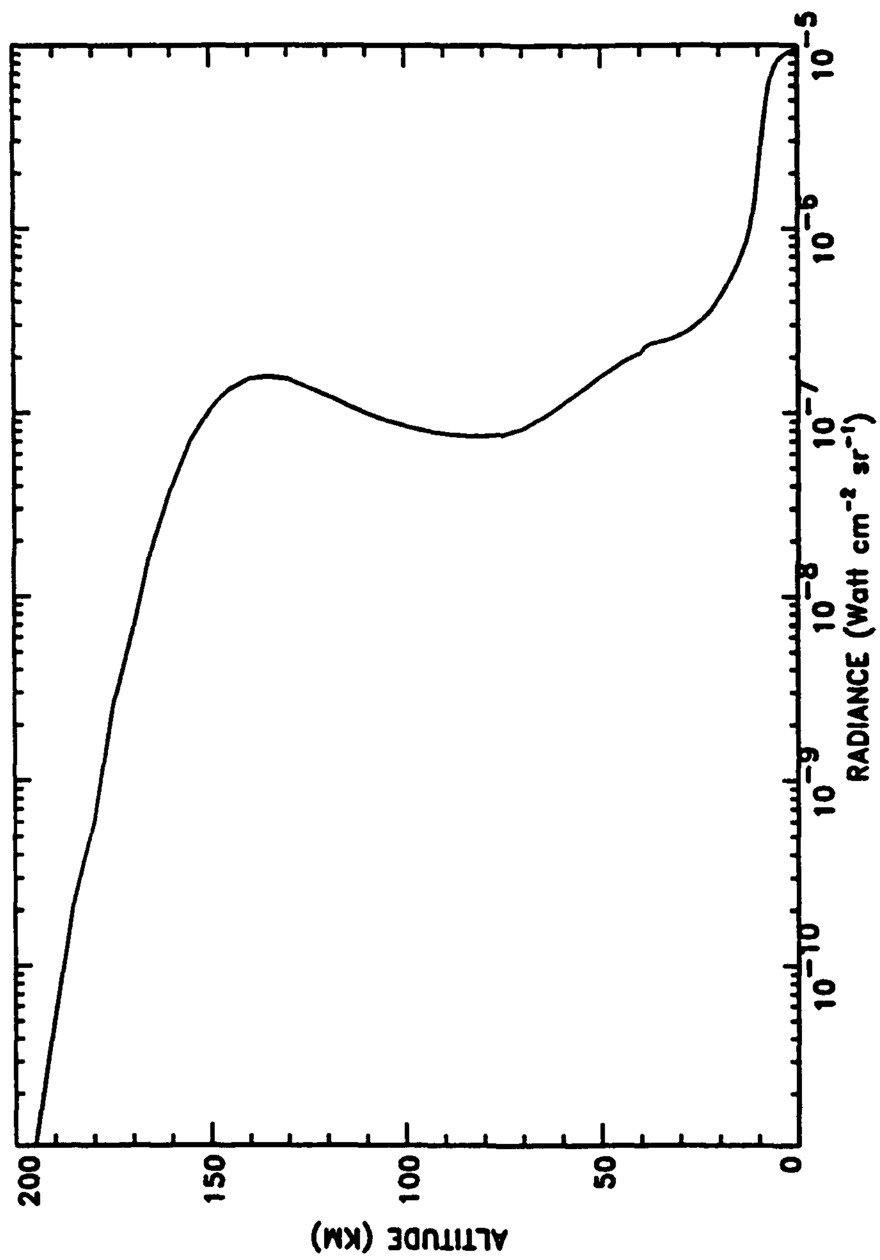

DAY BIN17 4.452 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶

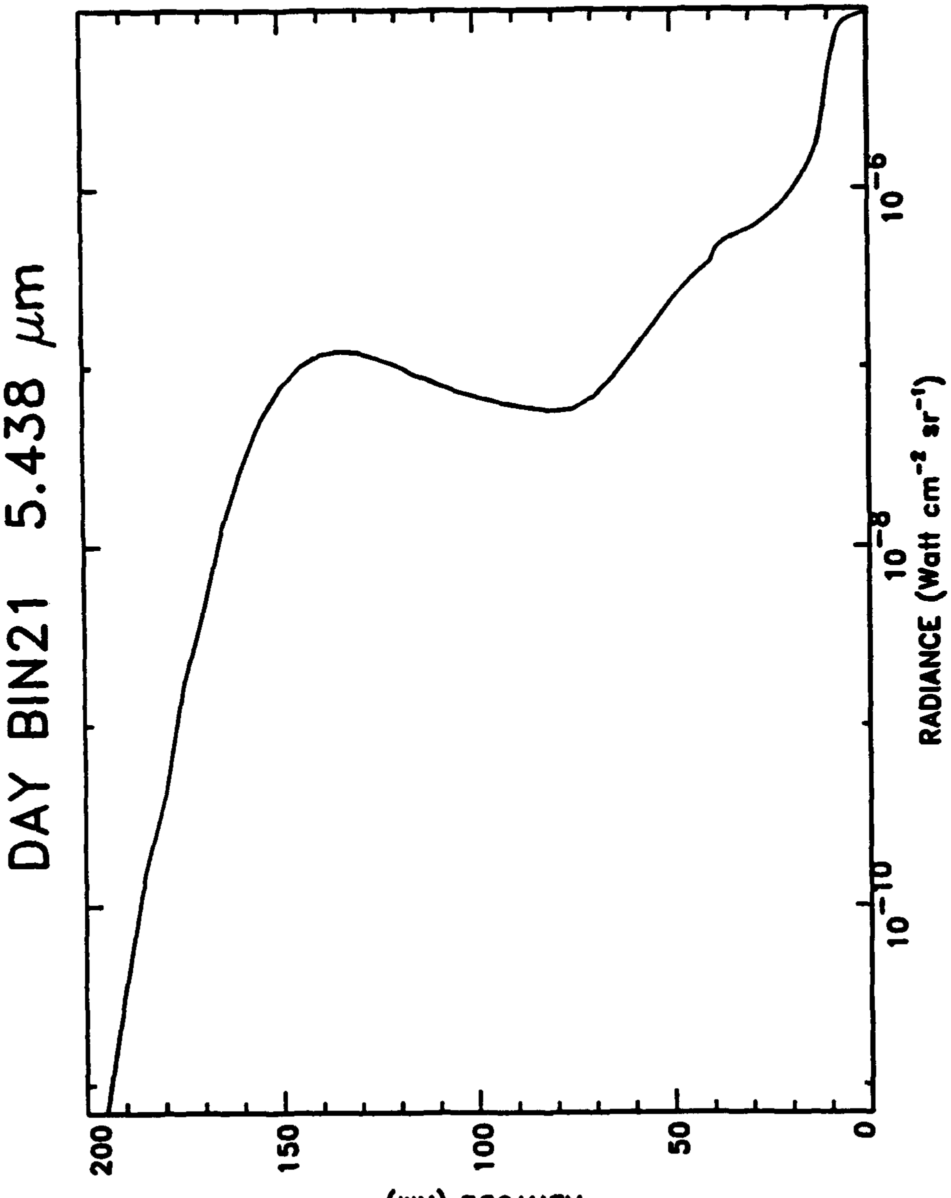

DAY BIN18 4.680 μm
ALTITUDE (KM)
200
150
100
50
0
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
RADIANCE (Watt cm⁻² sr⁻¹)

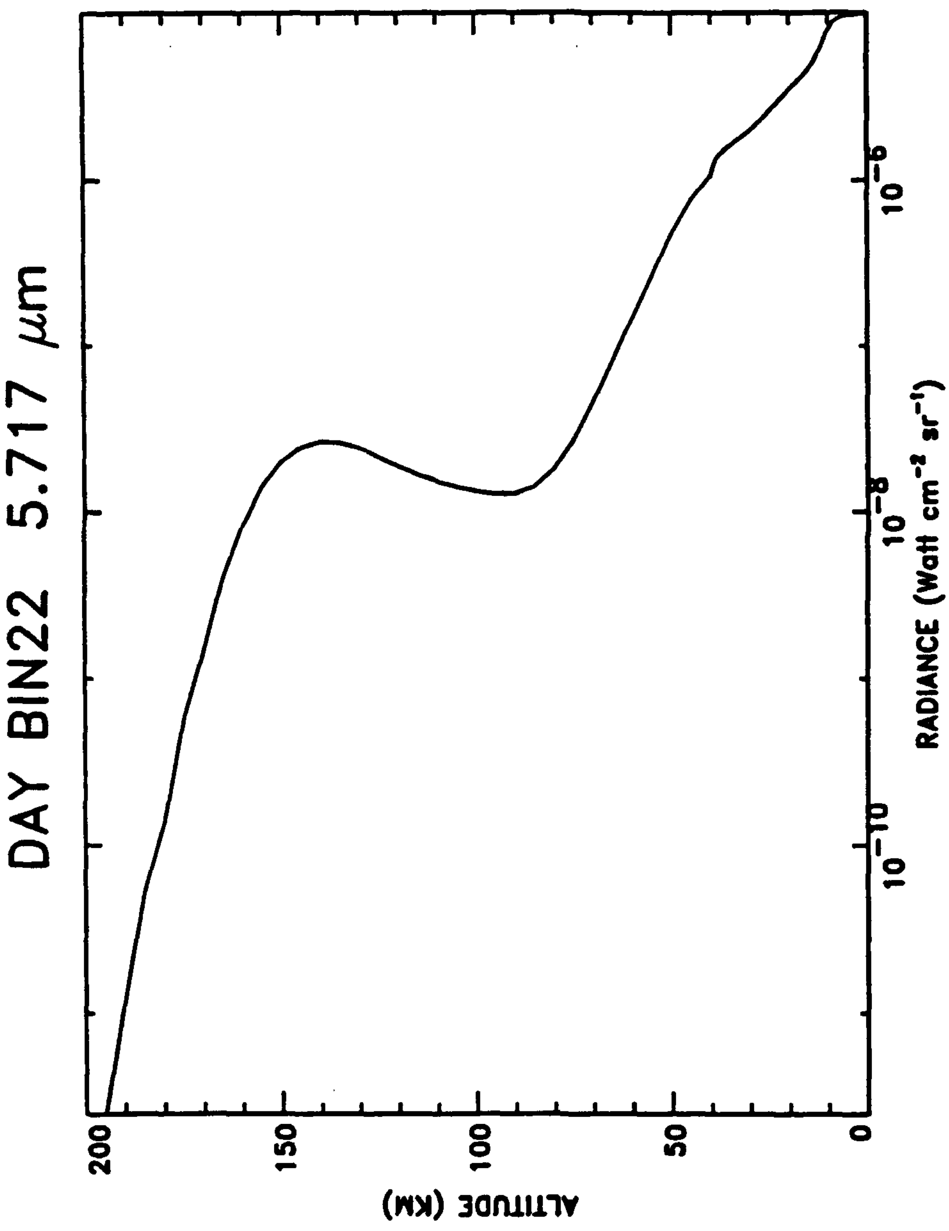
DAY BIN19 4.920 μm



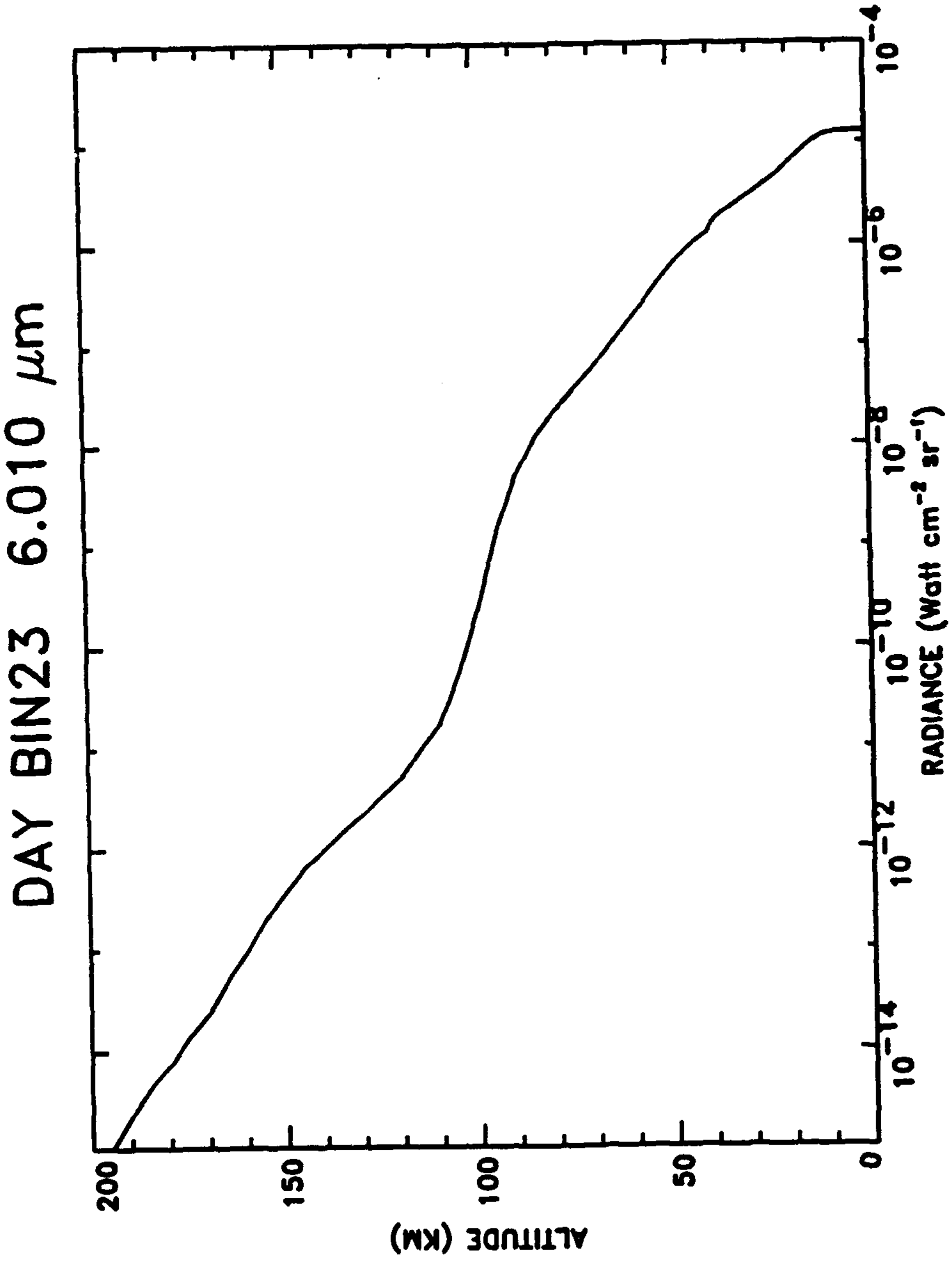
DAY BIN20 5.172 μm

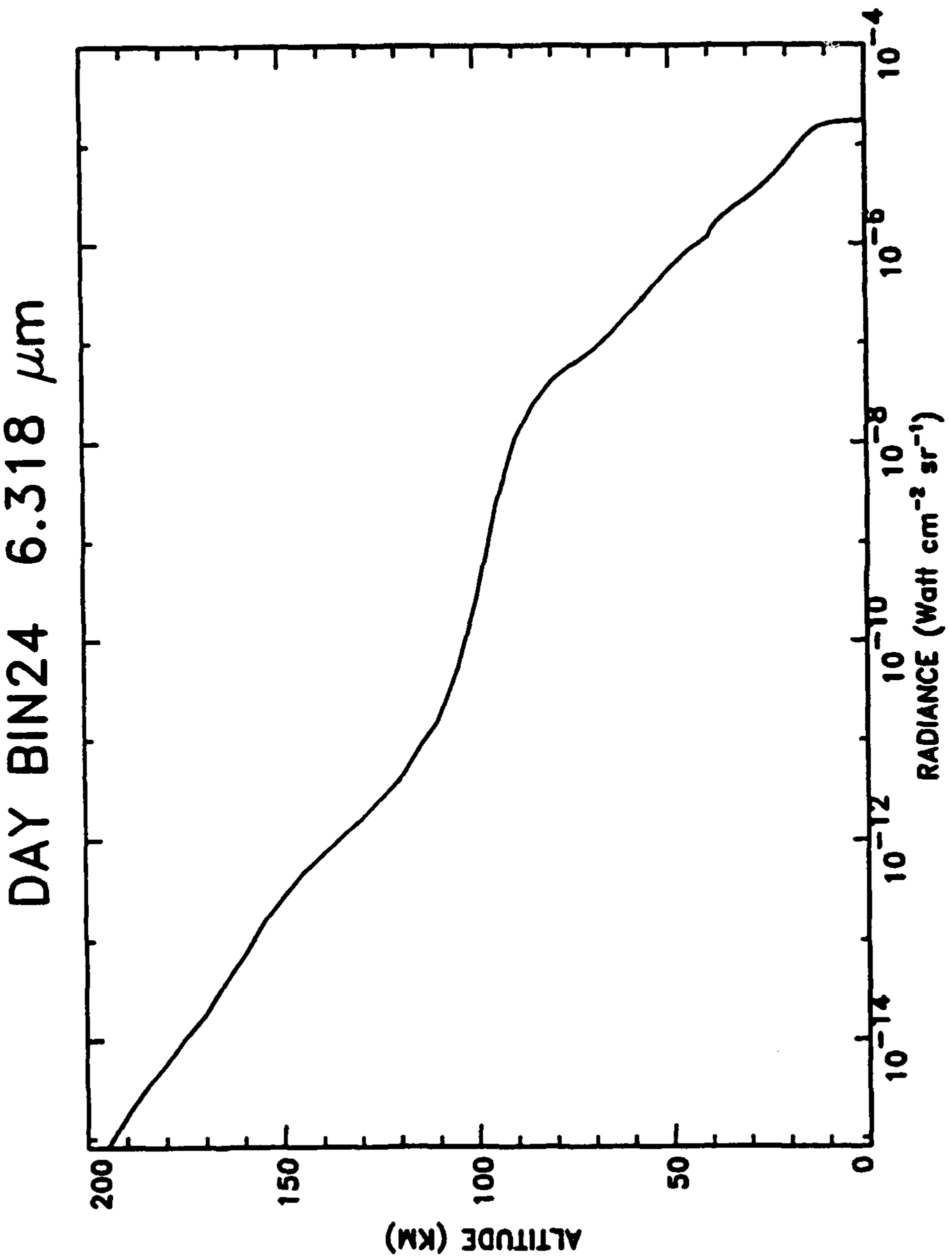



DAY BIN21 5.438 μm
ALTITUDE (KM)
0
50
100
150
200
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁰
10⁻⁸
10⁻⁶

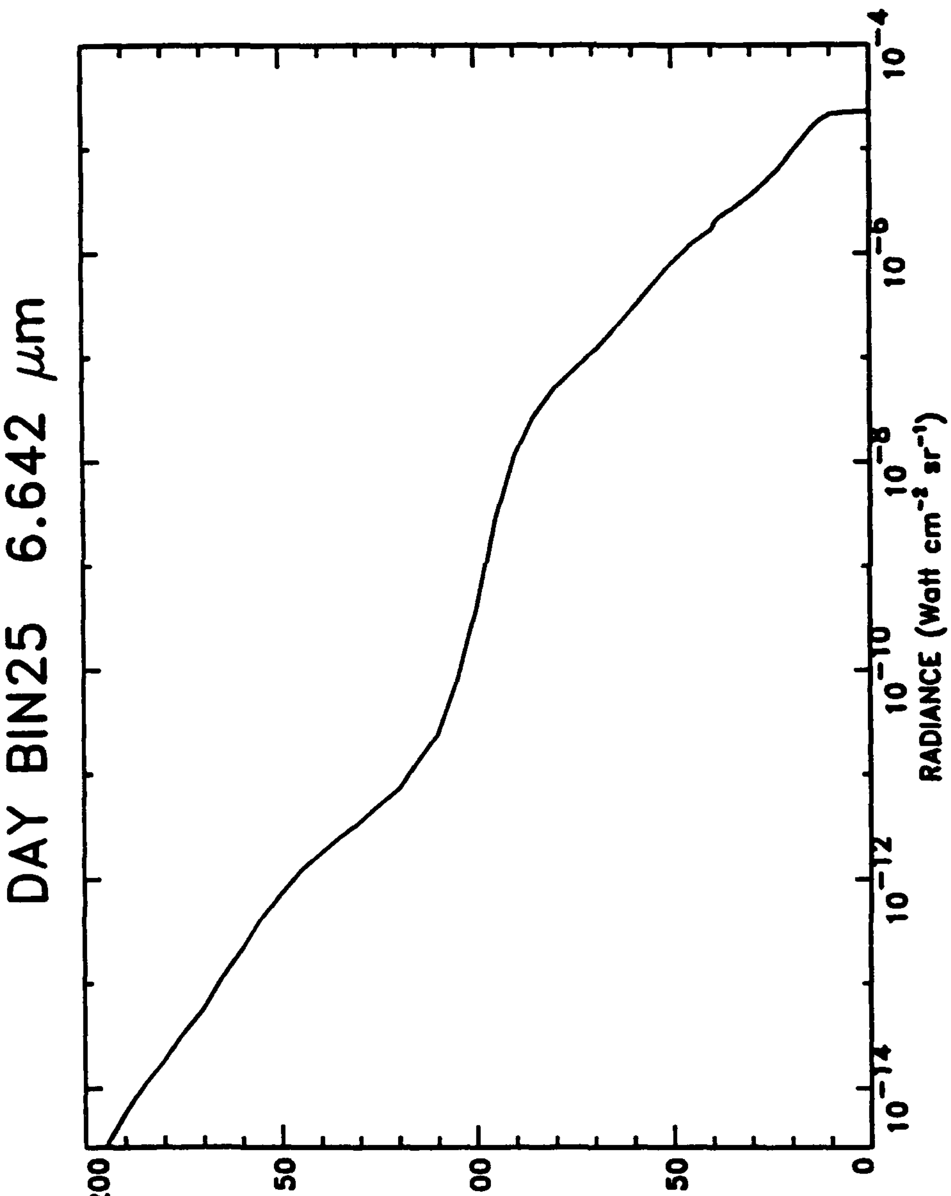


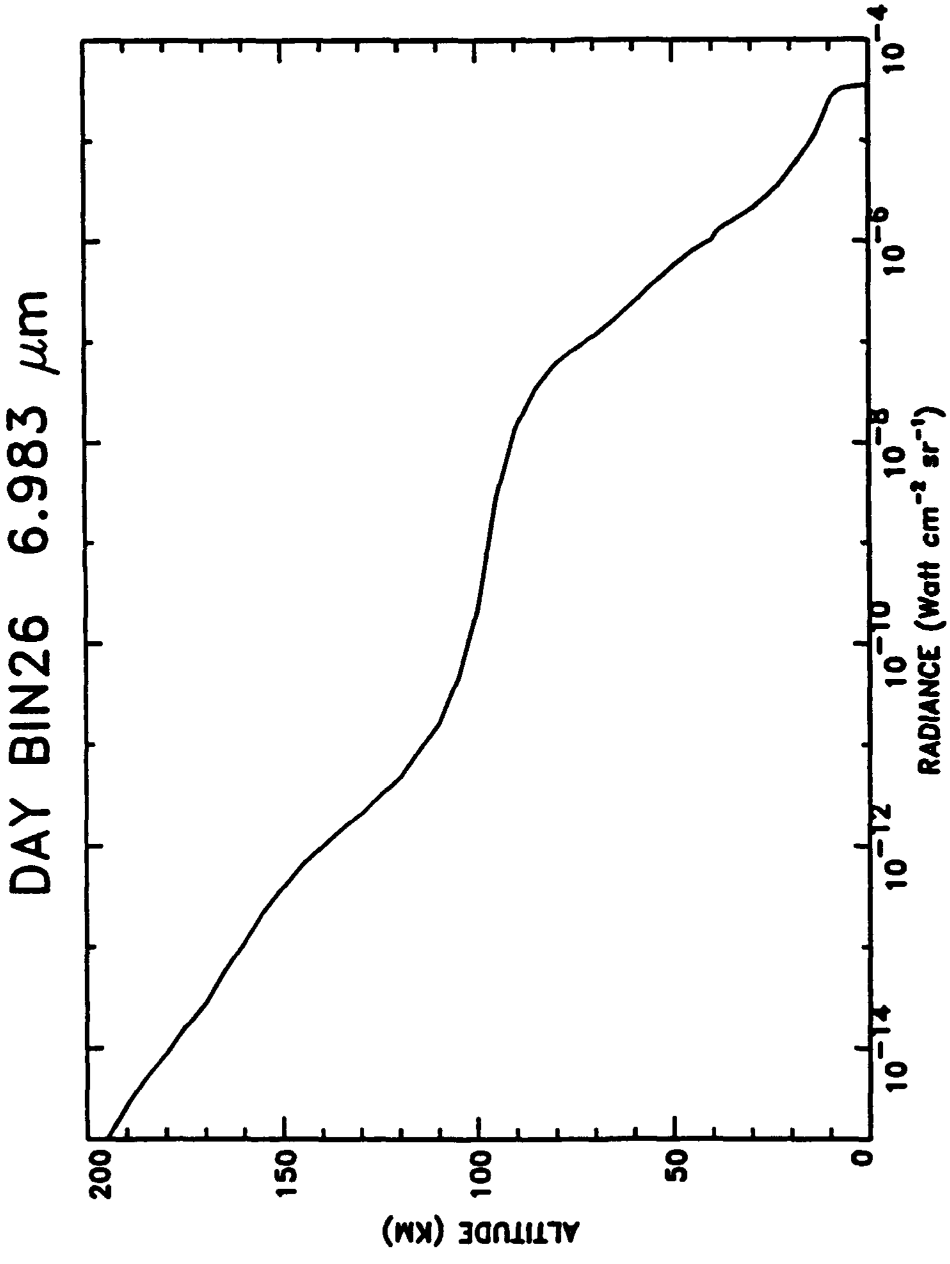
DAY BIN22 5.717 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-10}
10^{-8}
10^{-6}


DAY BIN23 6.010 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10^-14
10^-12
10^-10
10^-8
10^-6
10^-4

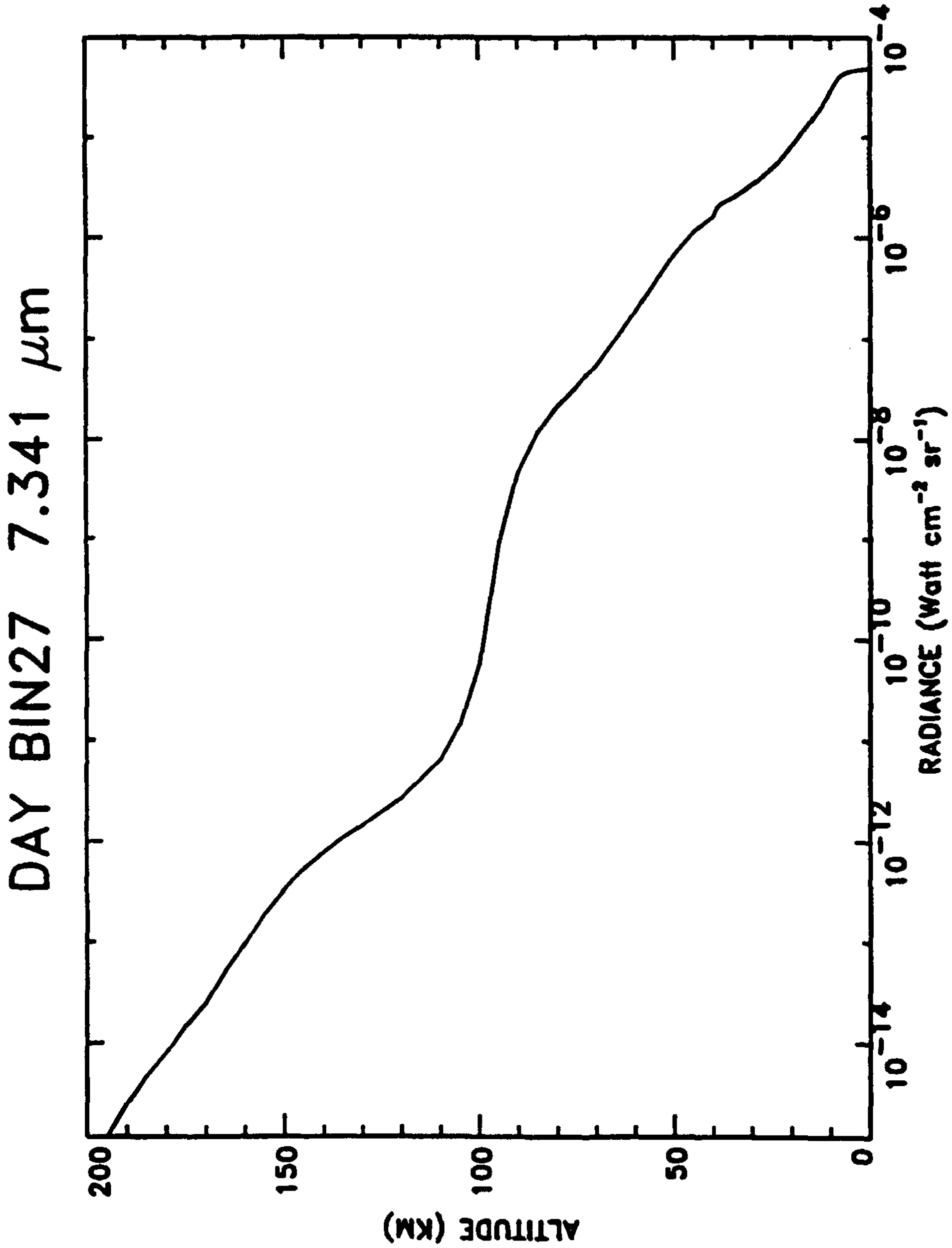


DAY BIN24 6.318 μm
ALTITUDE (KM)
RADIANCE (Watt cm⁻² sr⁻¹)
200
150
100
50
0
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

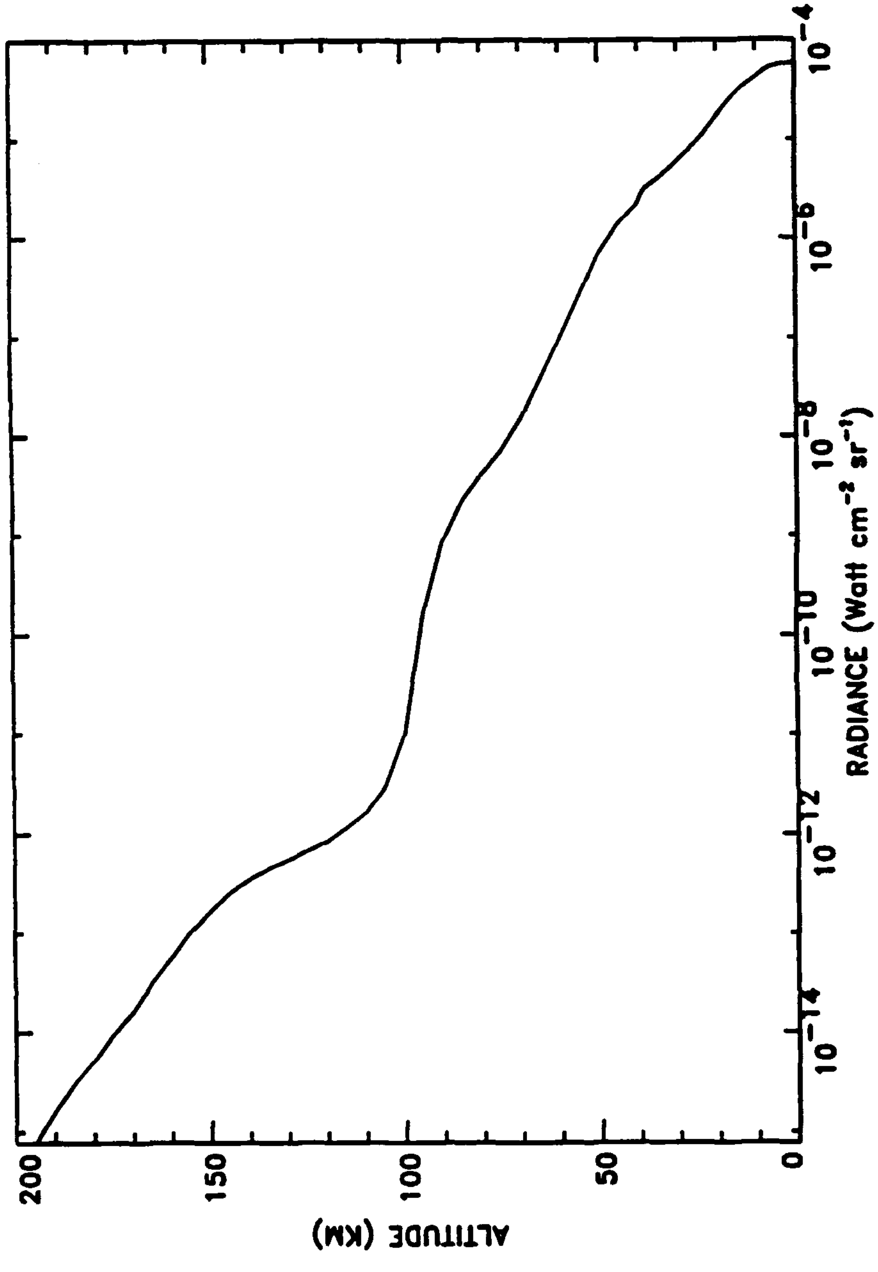

DAY BIN25 6.642 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}

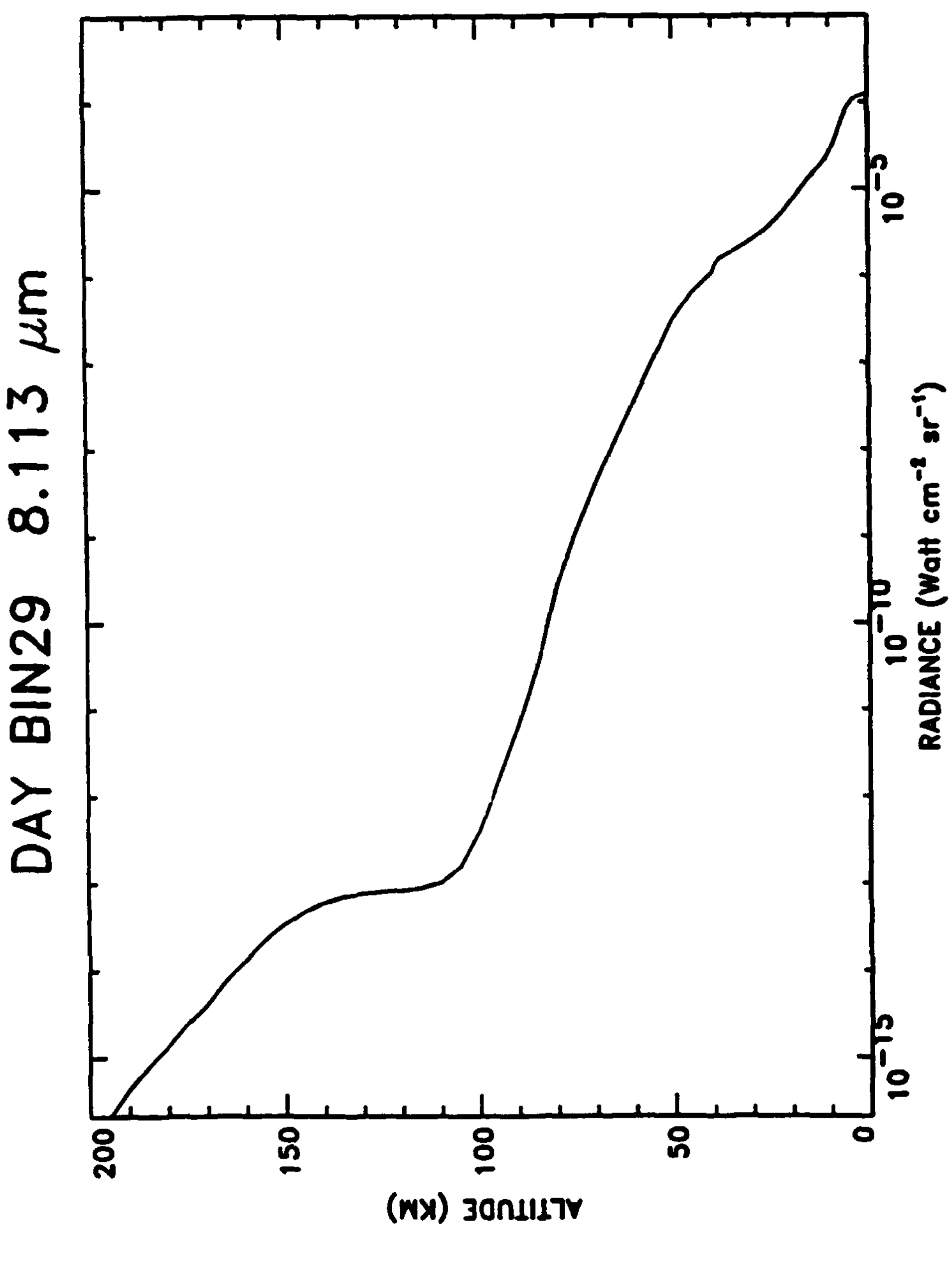


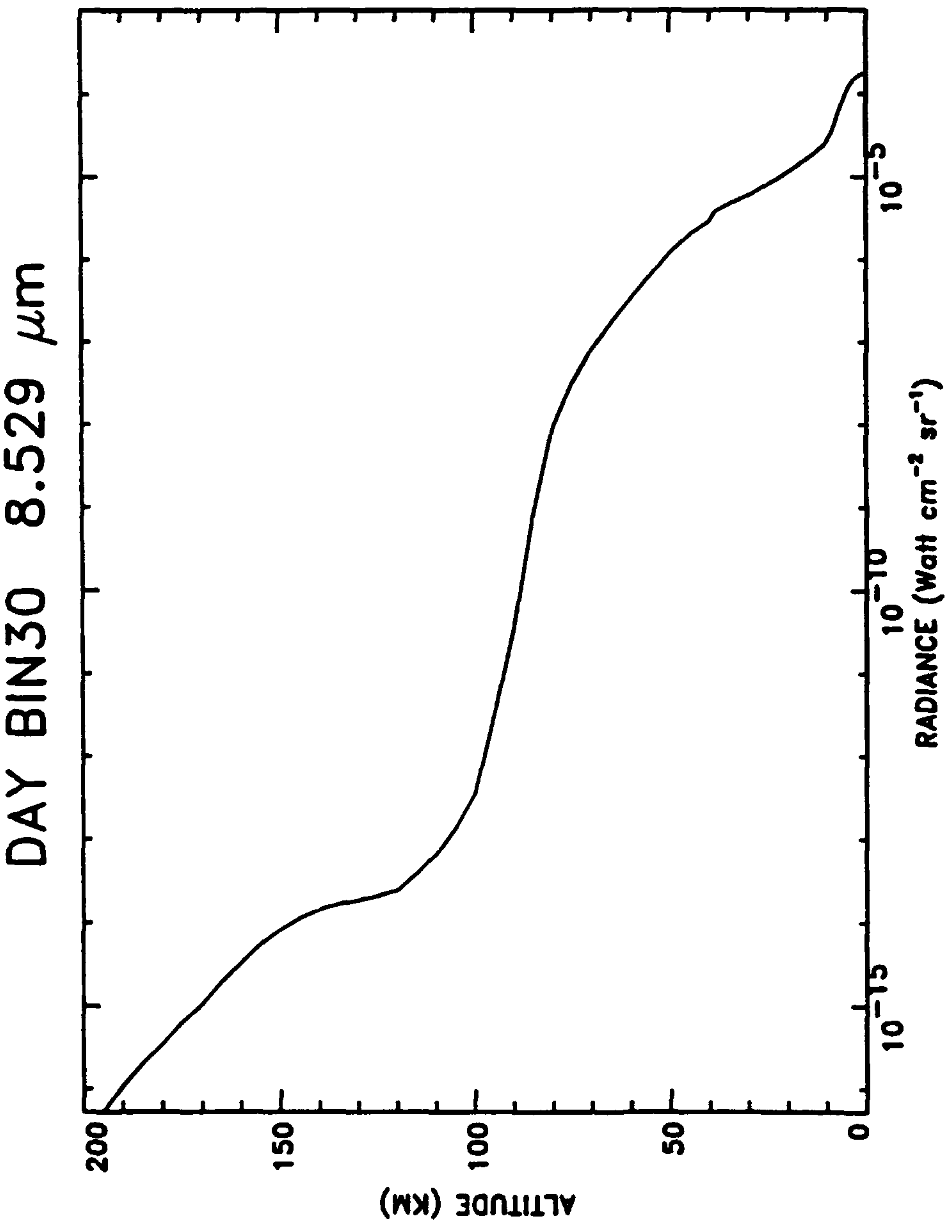
DAY BIN26 6.983 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴


DAY BIN27 7.341 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

DAY BIN28 7.717 μm

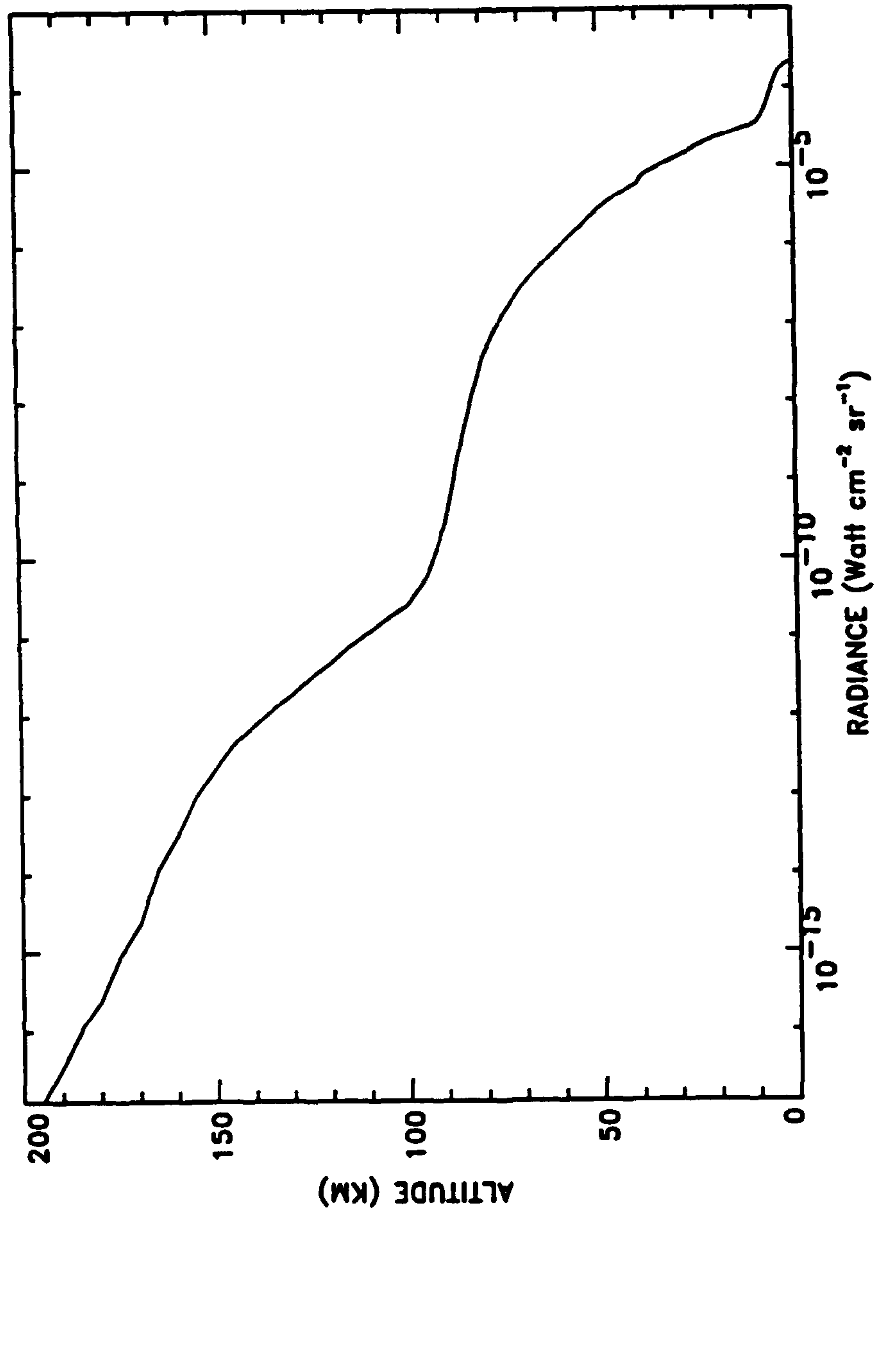


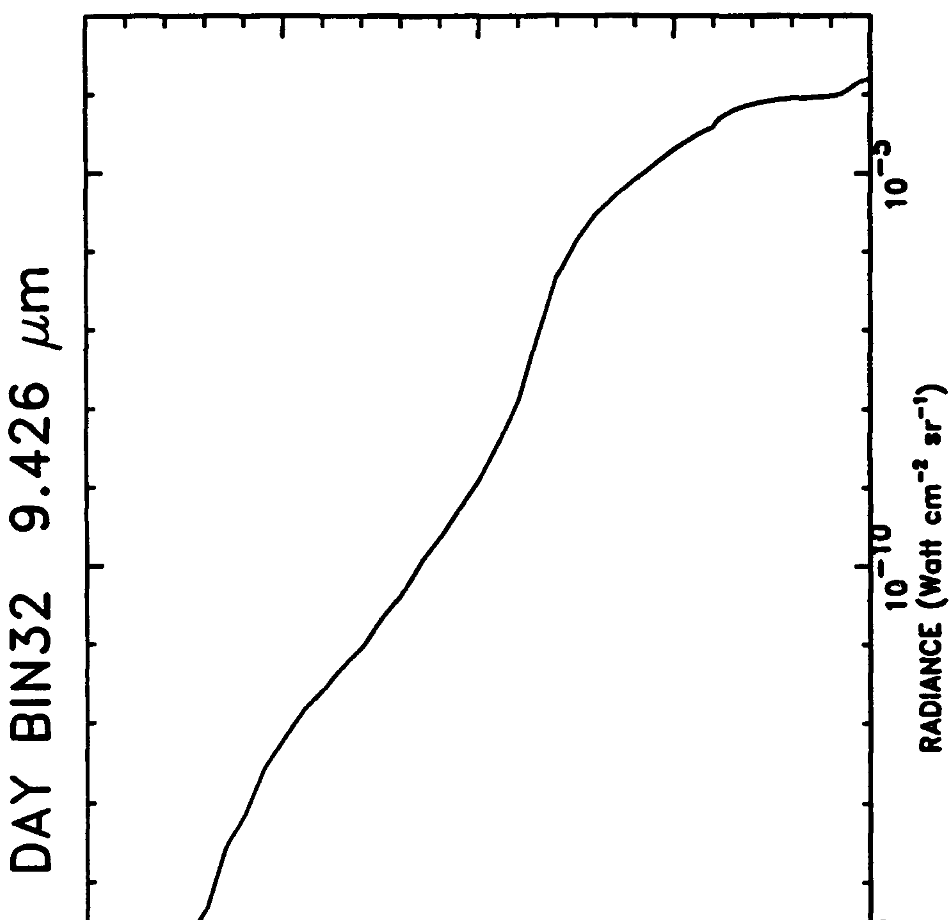

DAY BIN29 8.113 μm
ALTITUDE (KM)
200
150
100
50
0
10^-15
10^-10
10^-5
RADIANCE (Watt cm^-2 sr^-1)



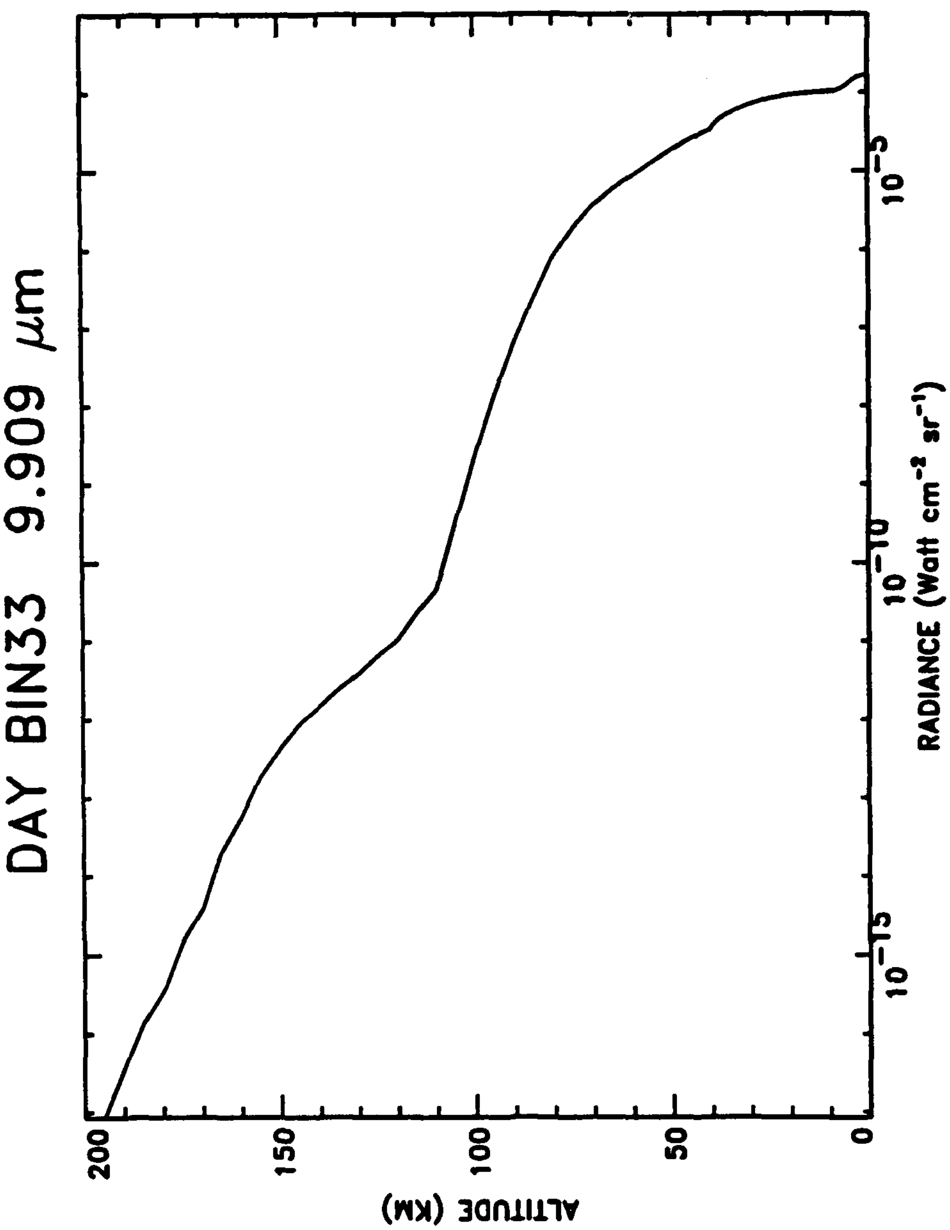
DAY BIN30 8.529 μm
ALTITUDE (KM)
200
150
100
50
0
10^−15
10^−10
10^−5
RADIANCE (Watt cm^−2 sr^−1)

DAY BIN31 8.966 μm

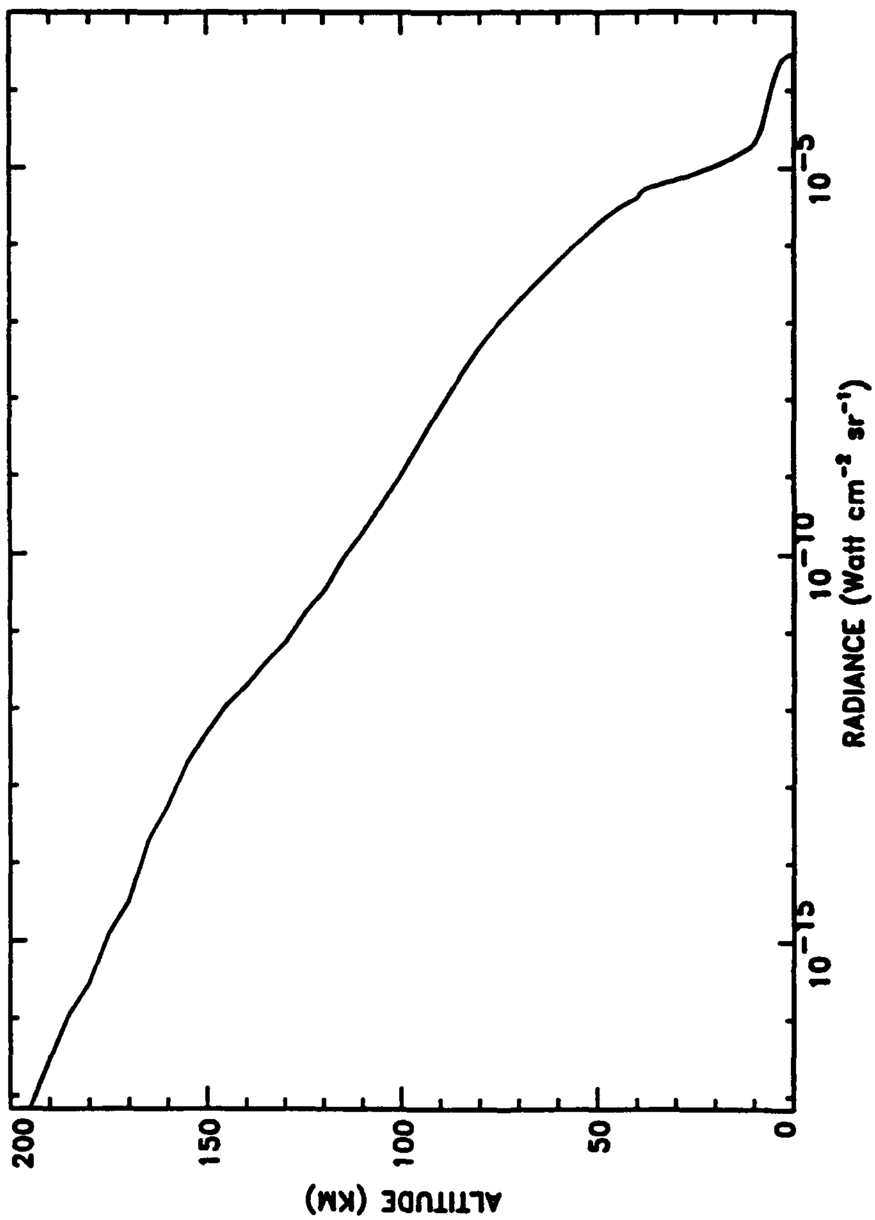


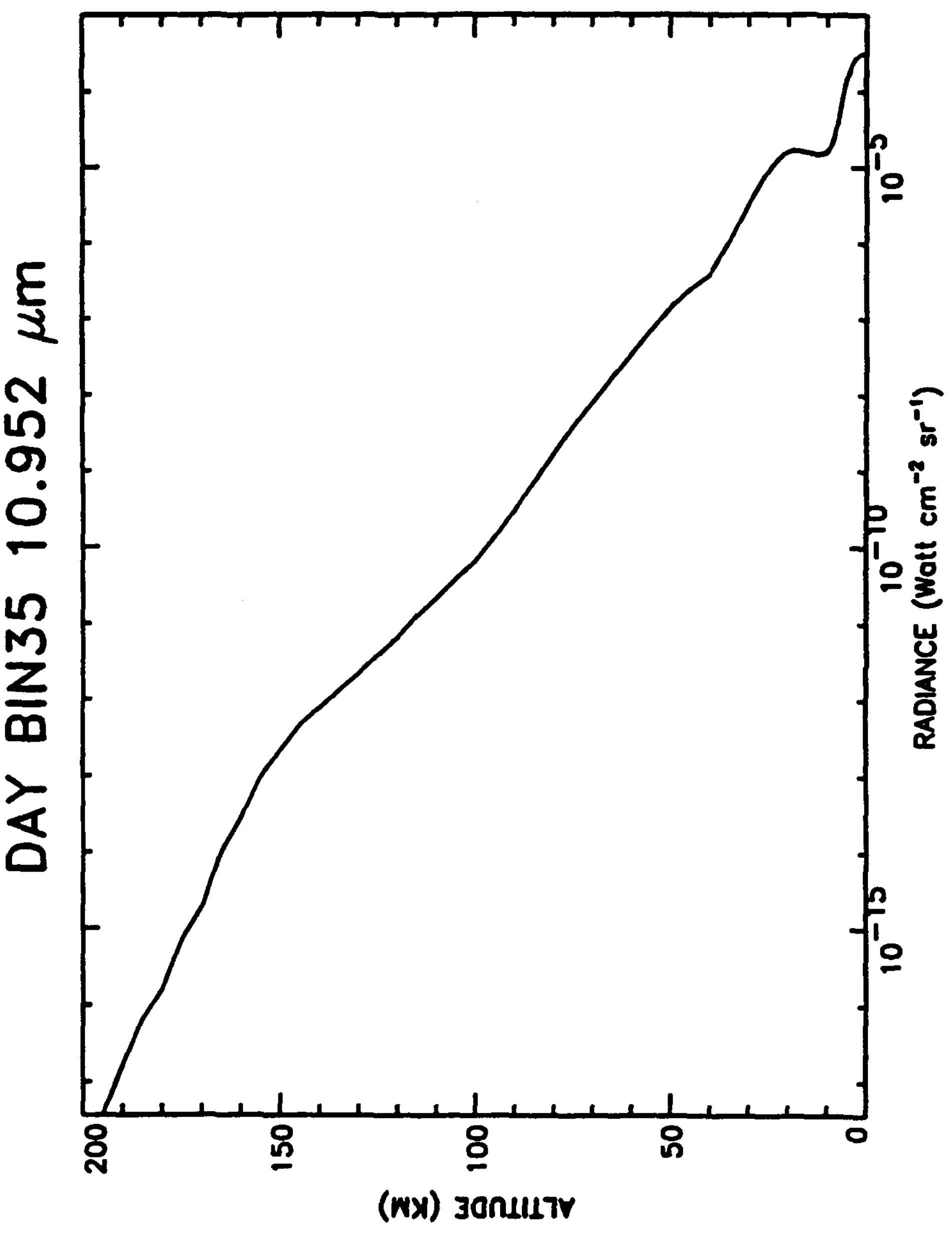


DAY BIN32 9.426 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁵
10⁻¹⁰
10⁻⁵

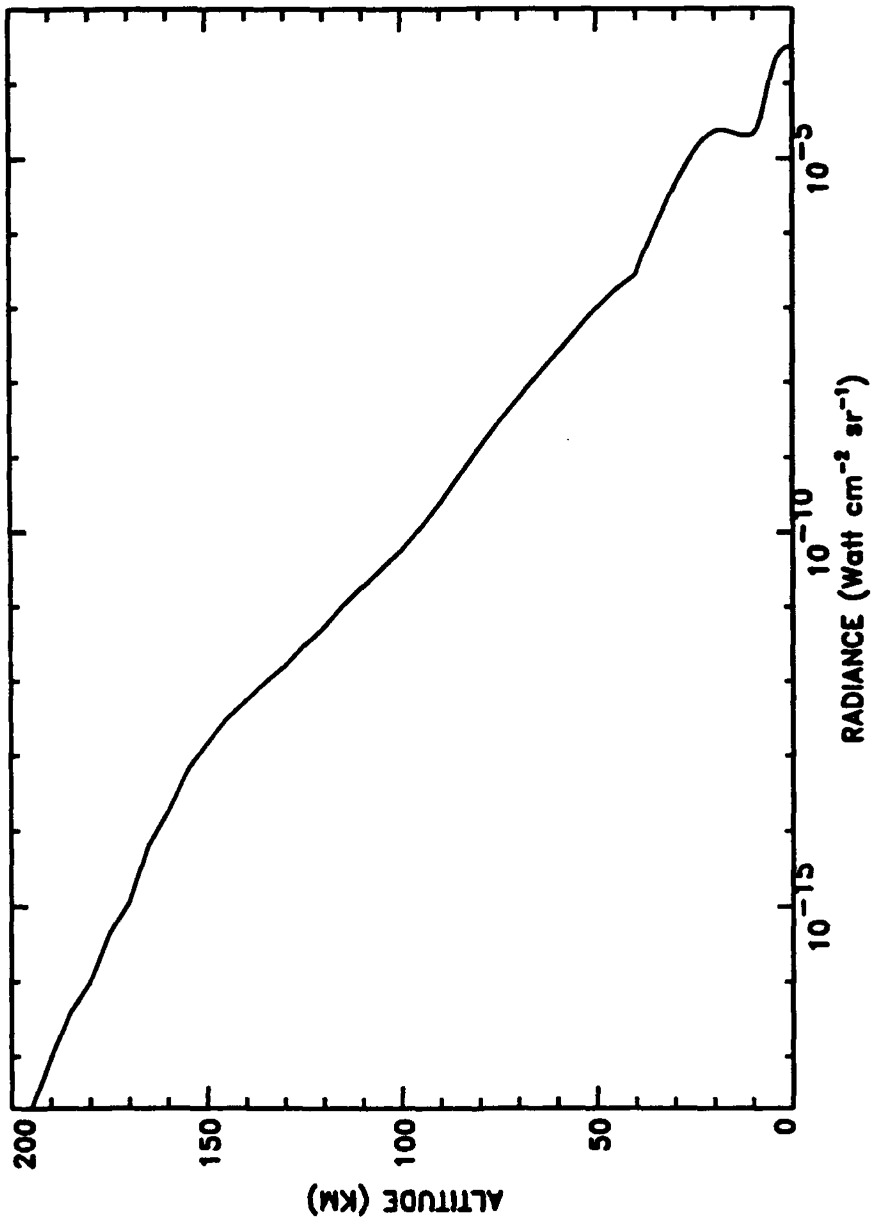

DAY BIN33 9.909 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁵
10⁻¹⁰
10⁻⁵

DAY BIN34 10.418 μm

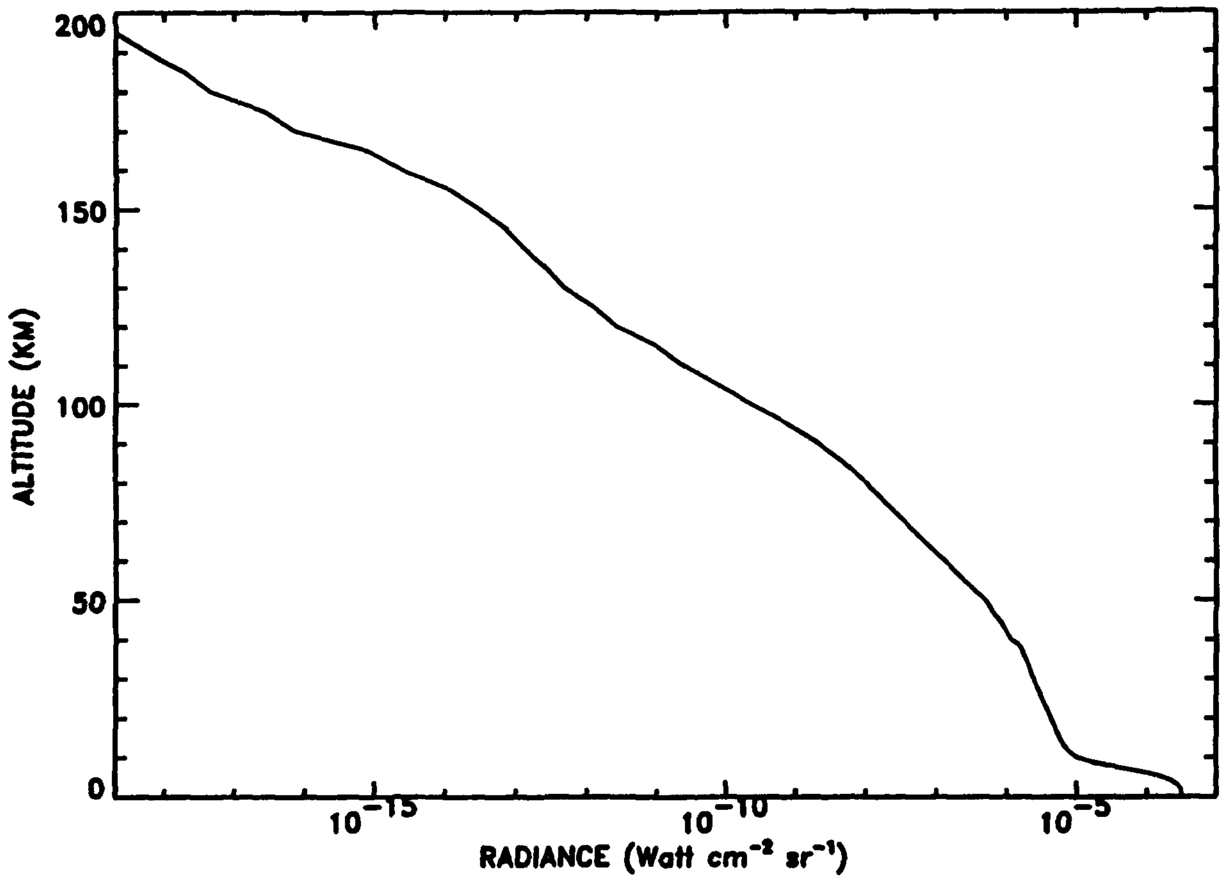



DAY BIN35 10.952 μm
ALTITUDE (KM)
200
150
100
50
0
10^{-15}
10^{-10}
10^{-5}
RADIANCE (Watt cm^{-2} sr^{-1})

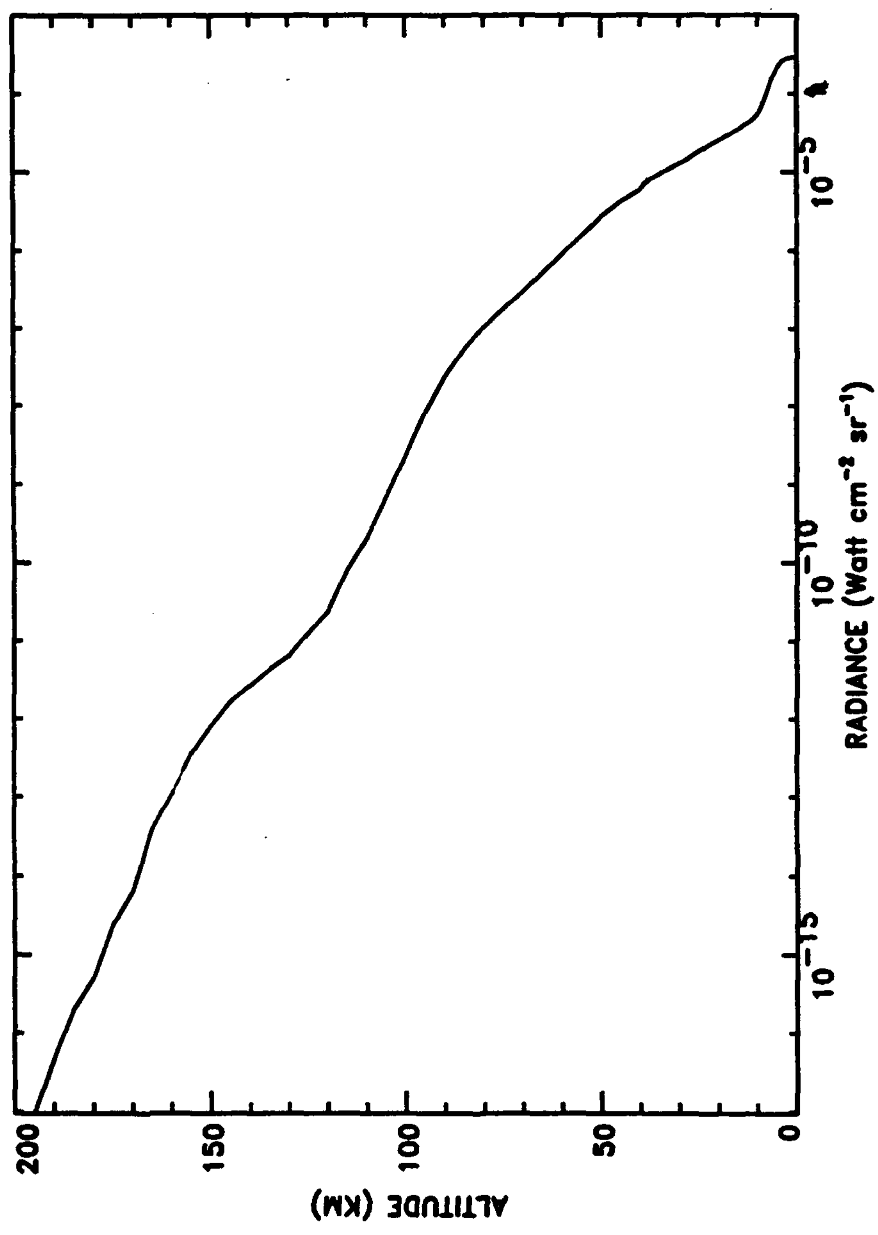
DAY BIN36 11.513 μm



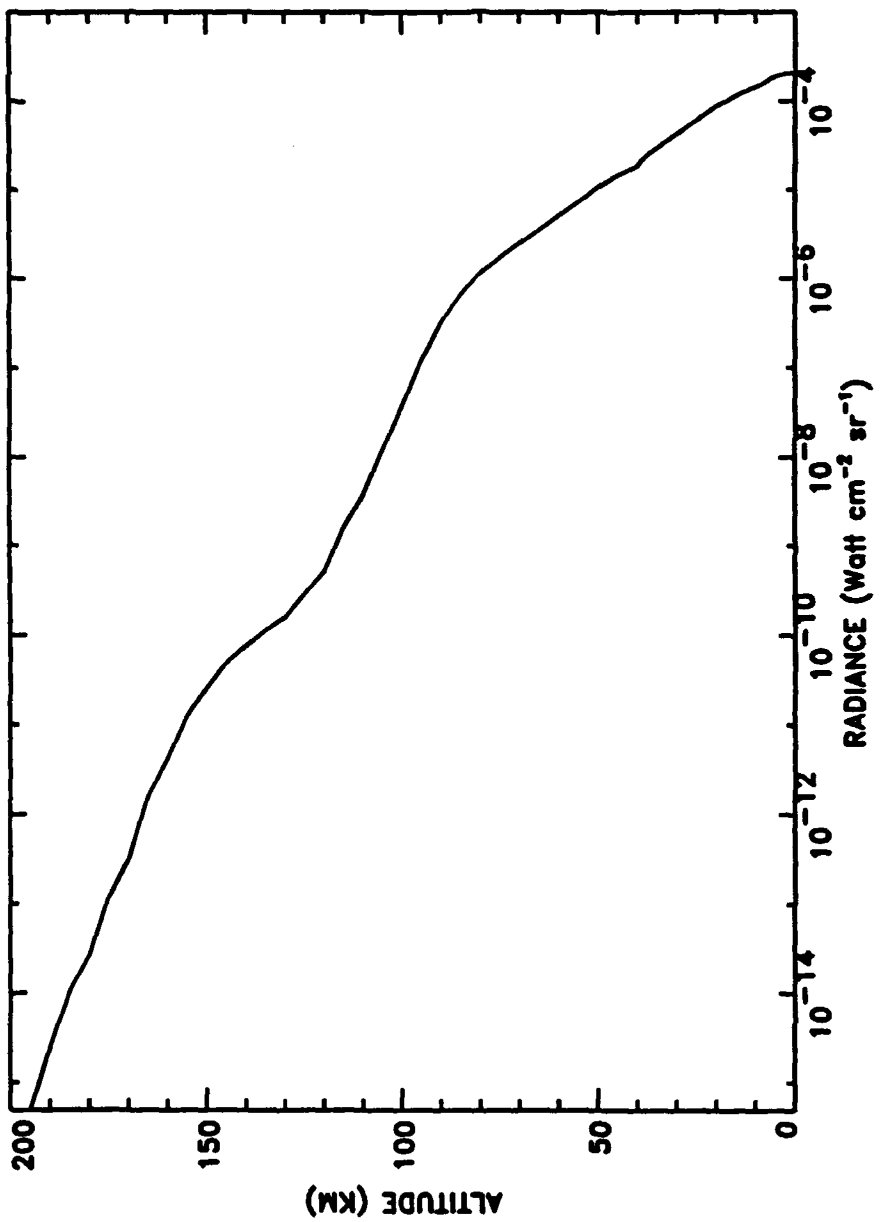
DAY BIN37 12.104 μm



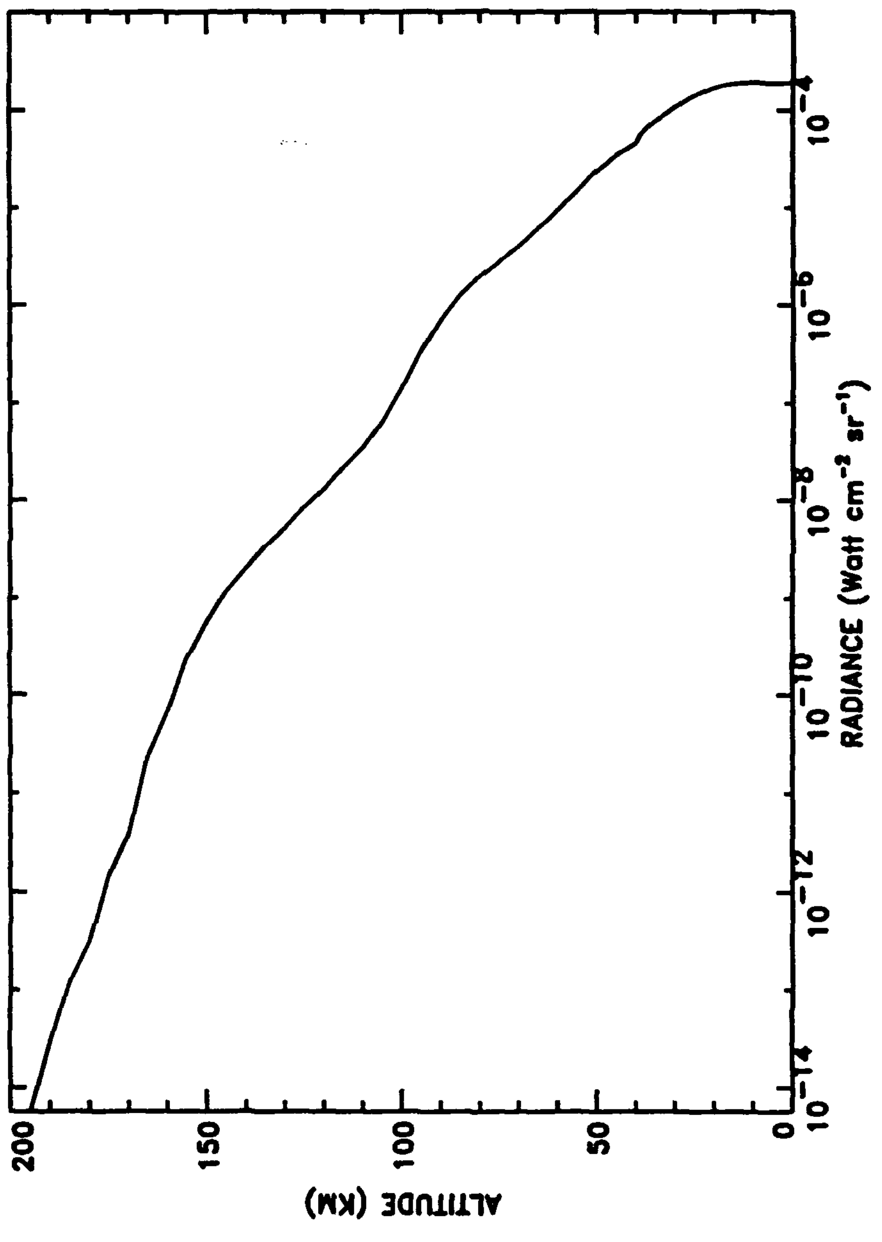
DAY BIN38 12.725 μm

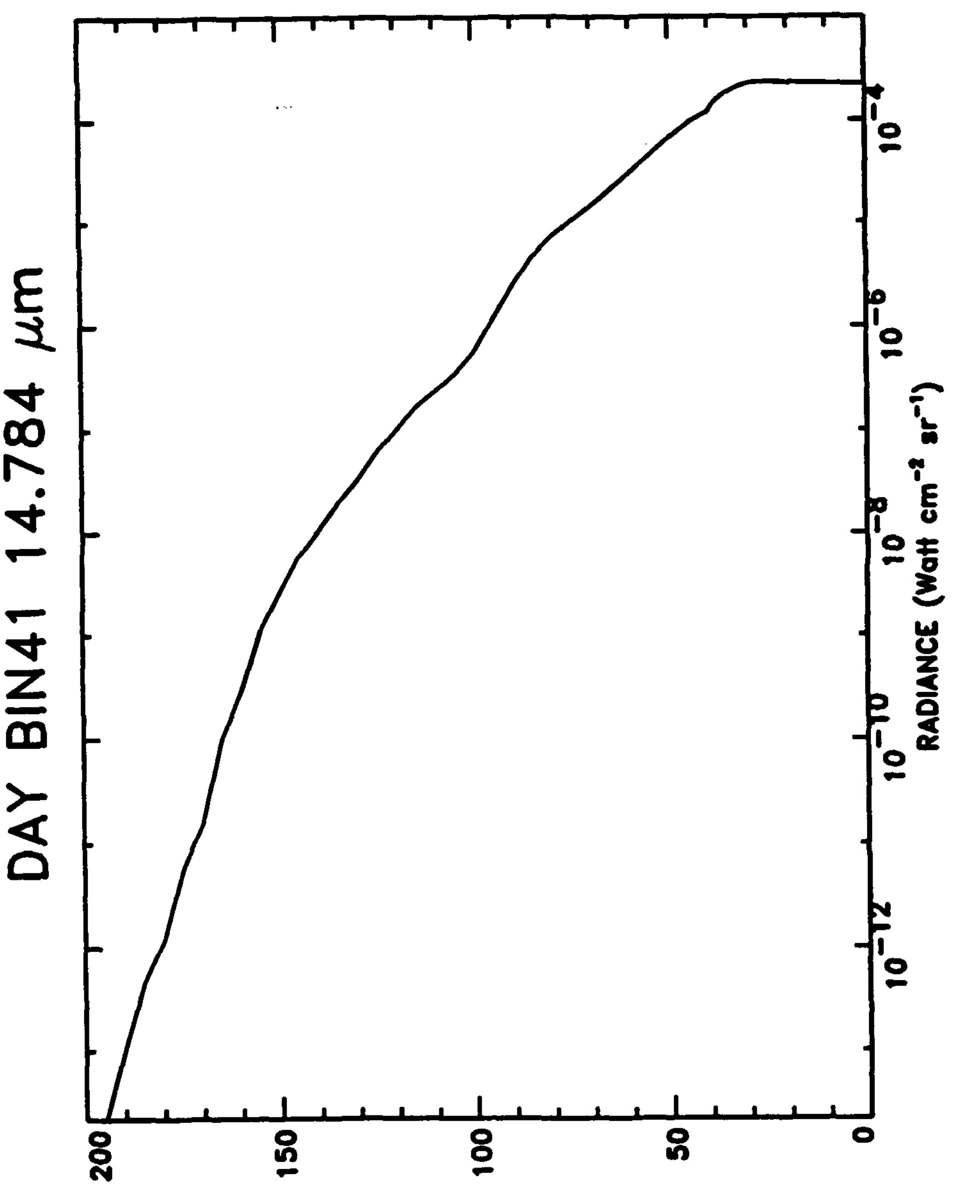


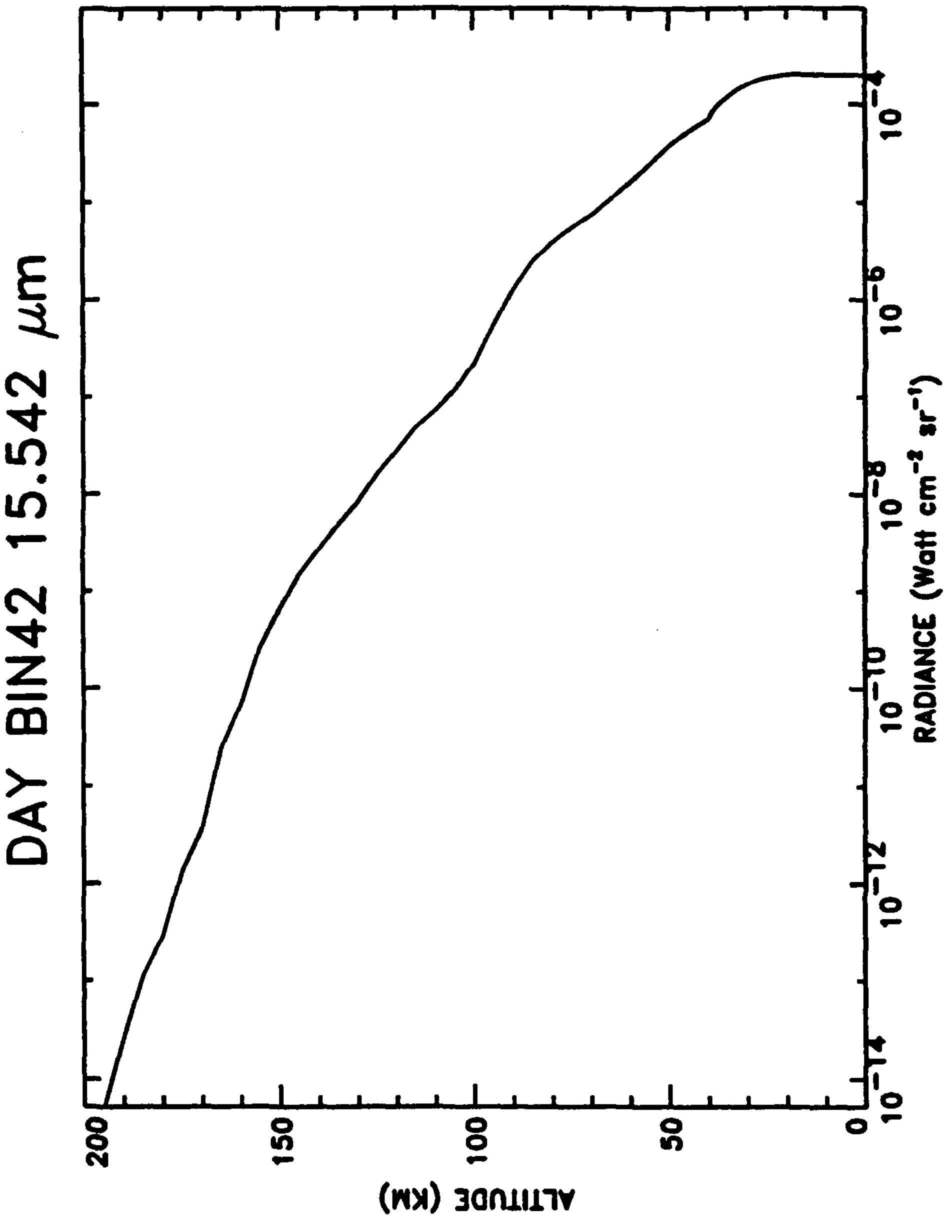
DAY BIN39 13.377 μm



DAY BIN40 14.063 μm

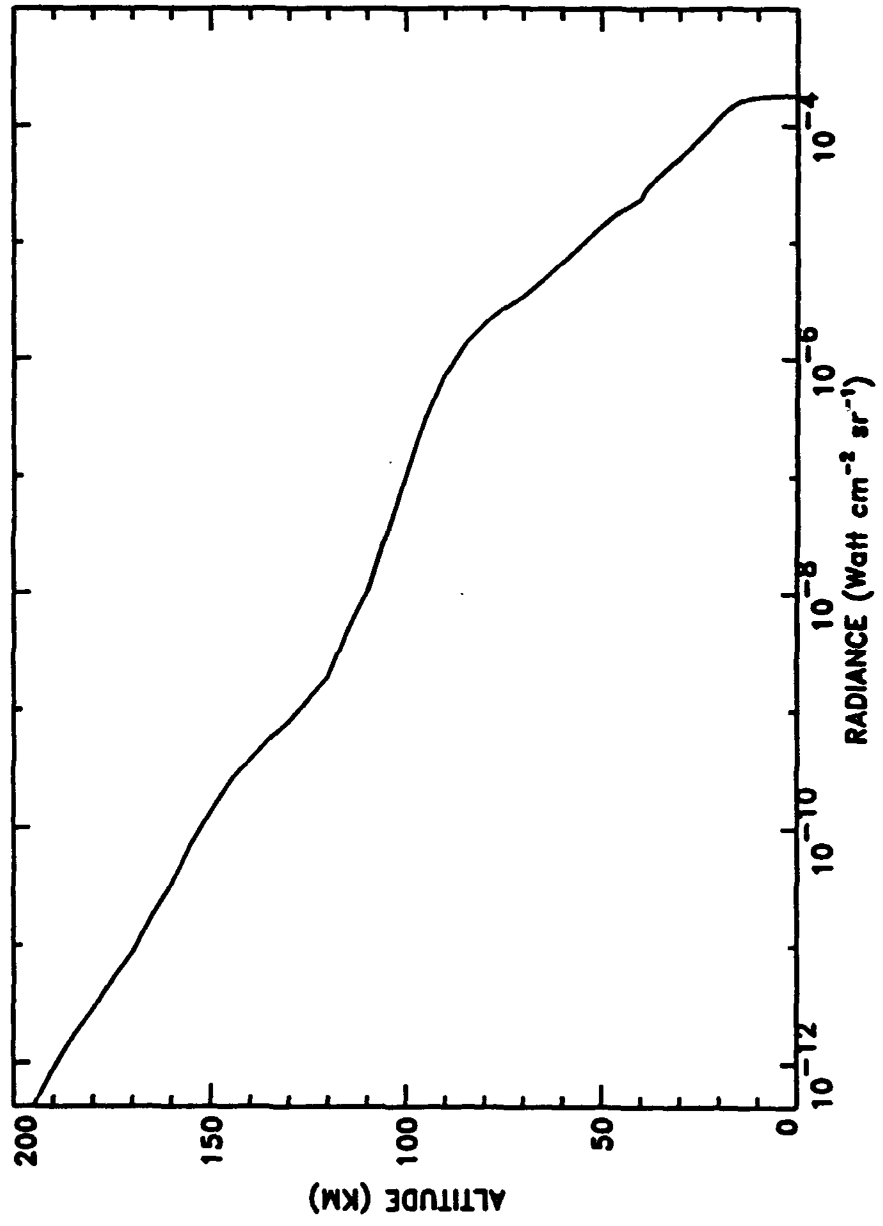


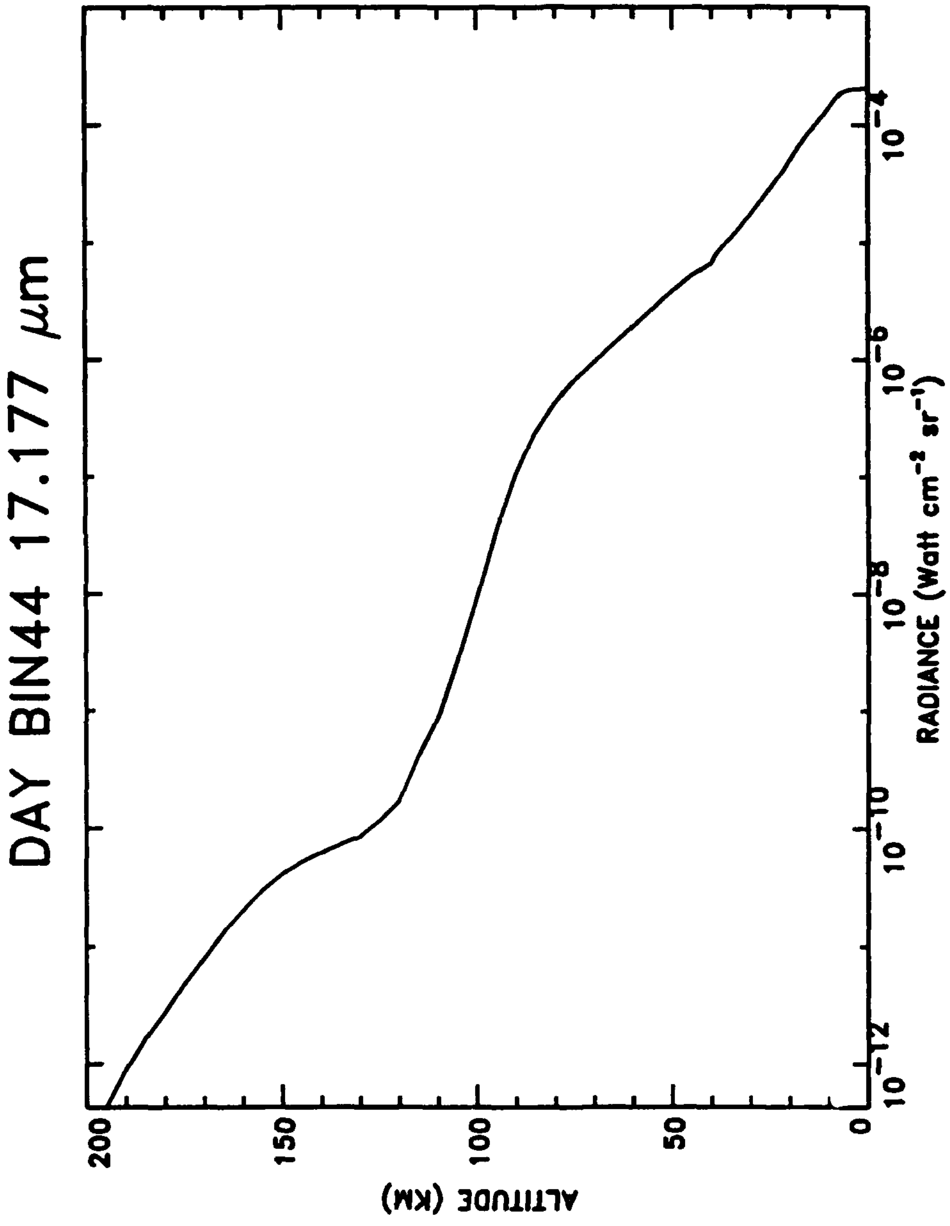

DAY BIN41 14.784 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

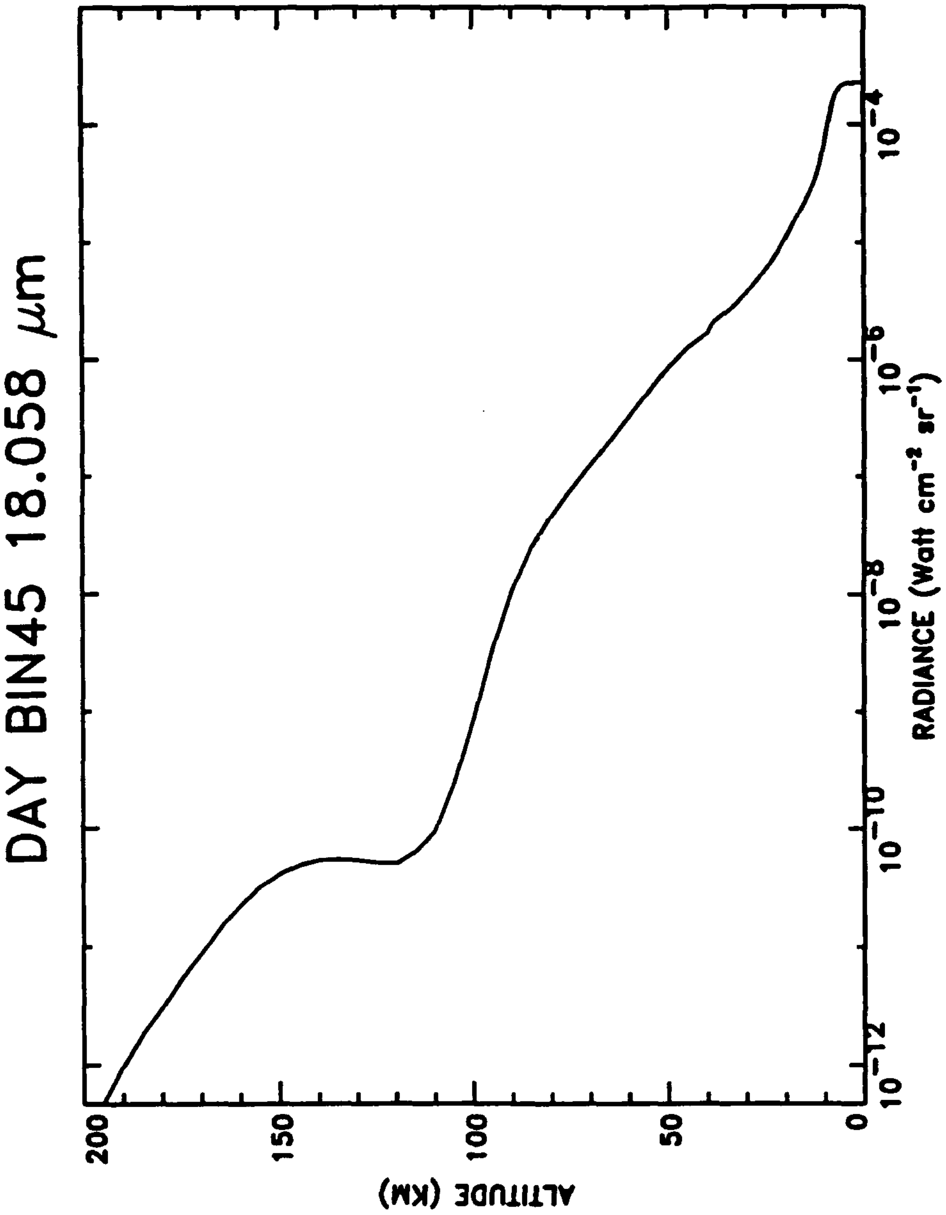


DAY BIN42 15.542 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

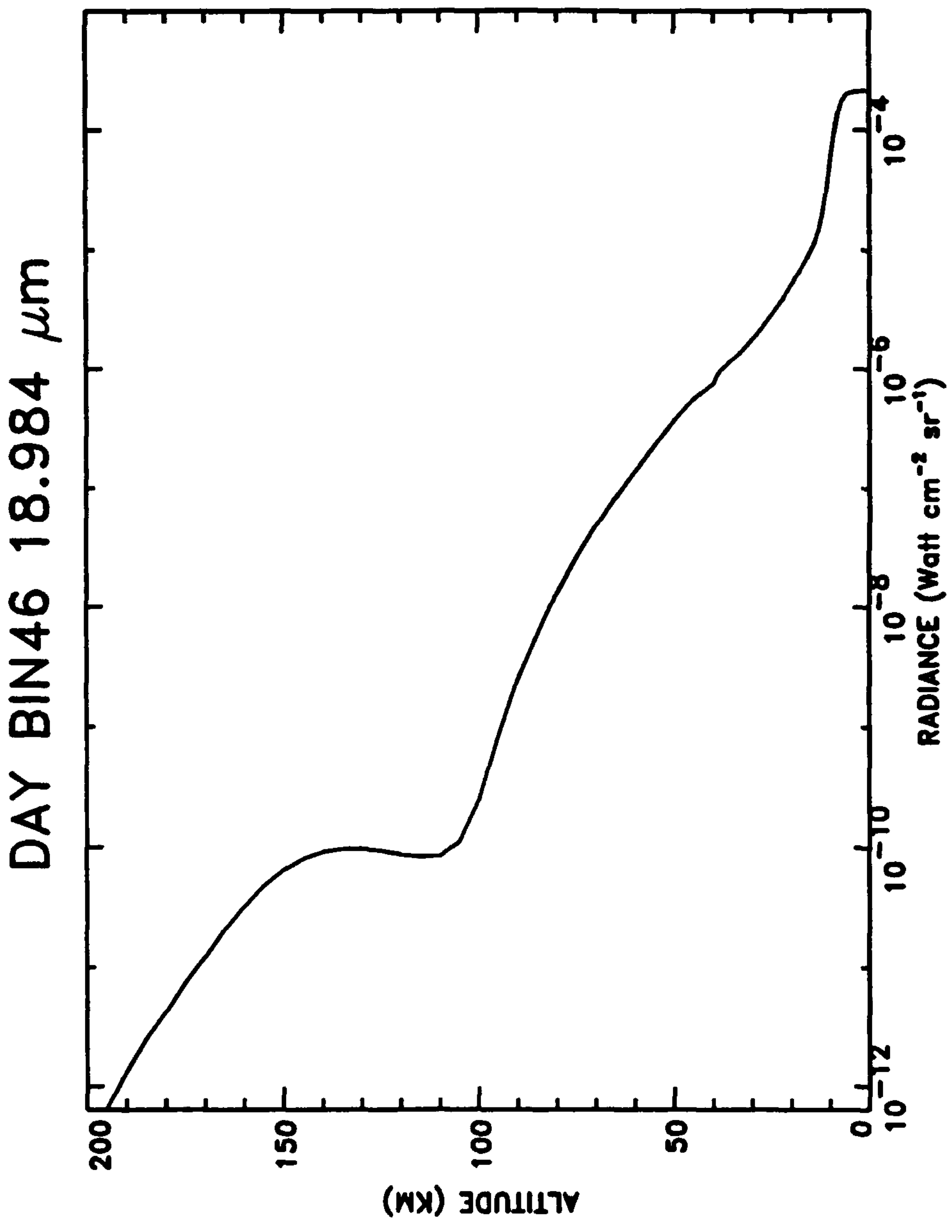
DAY BIN43 16.339 μm



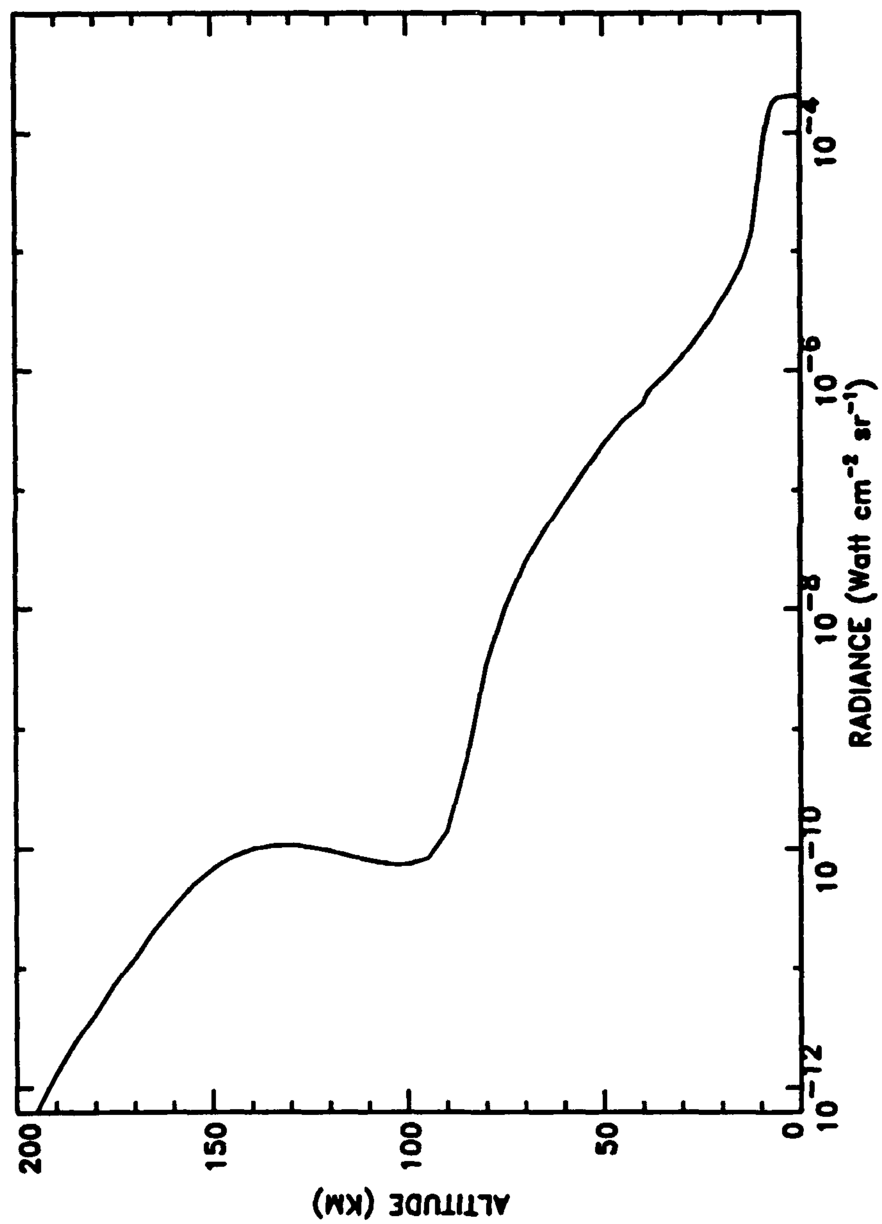

DAY BIN44 17.177 μm
ALTITUDE (KM)
200
150
100
50
0
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
RADIANCE (Watt cm^{-2} sr^{-1})

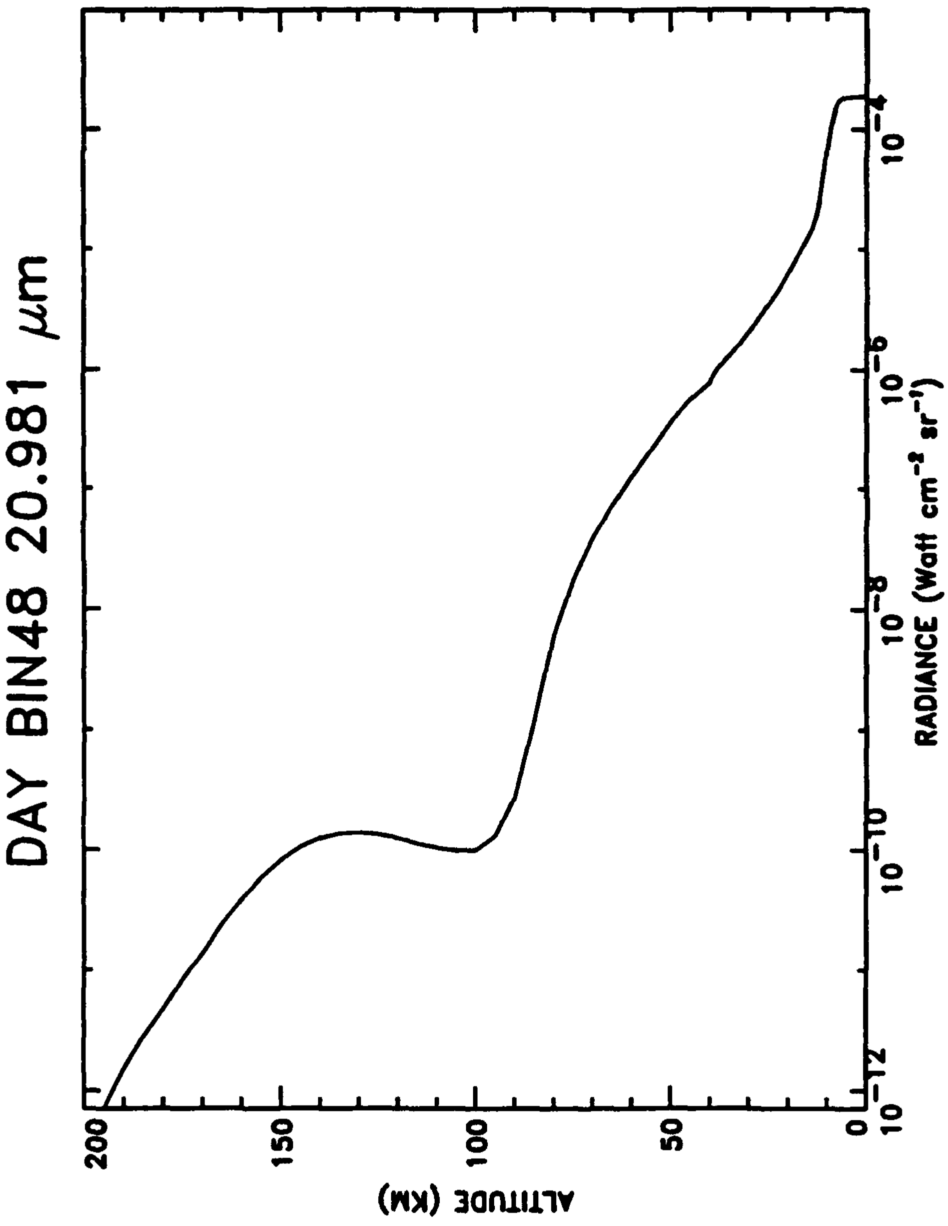


DAY BIN45 18.058 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}

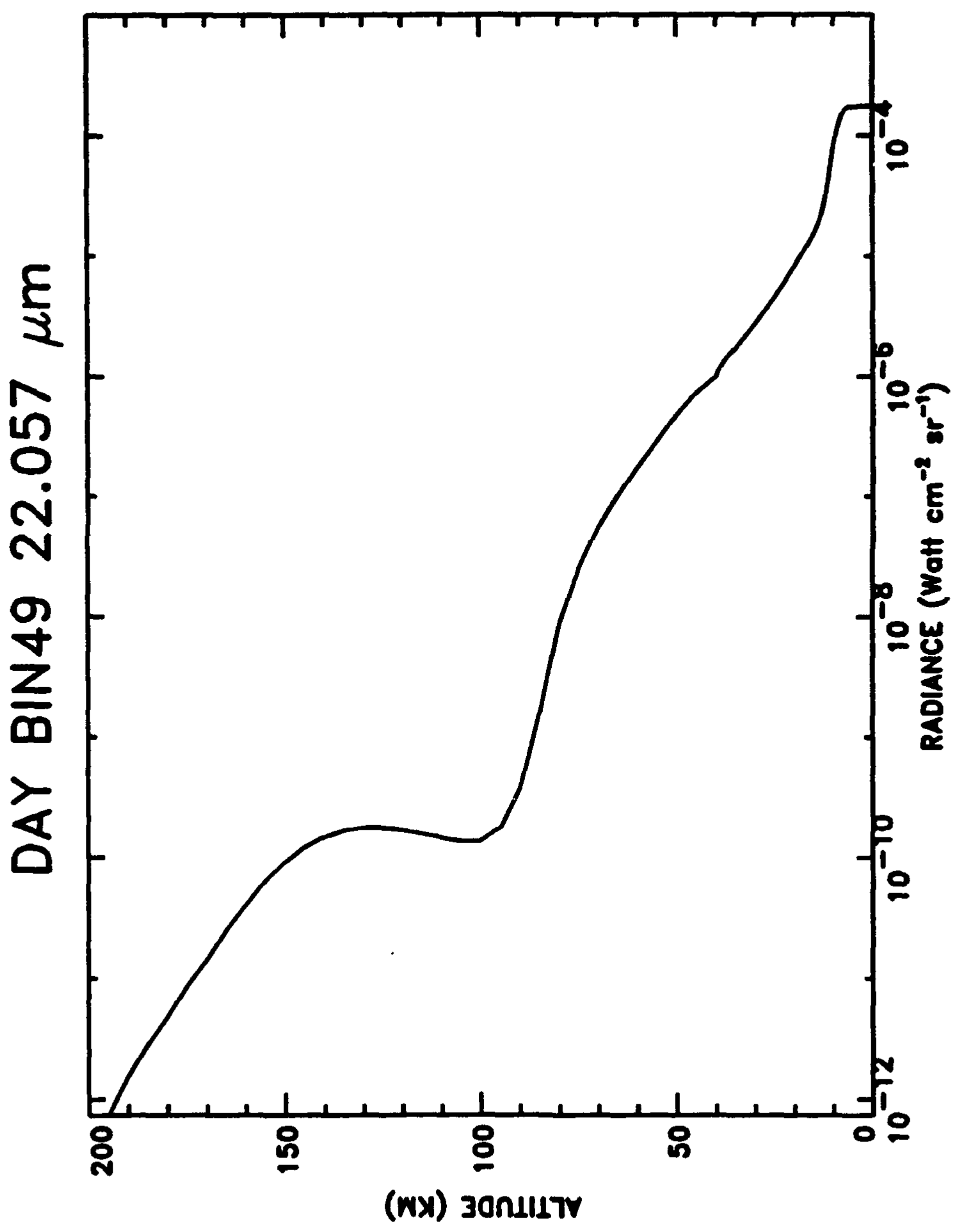

DAY BIN46 18.984 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

DAY BIN47 19.958 μm

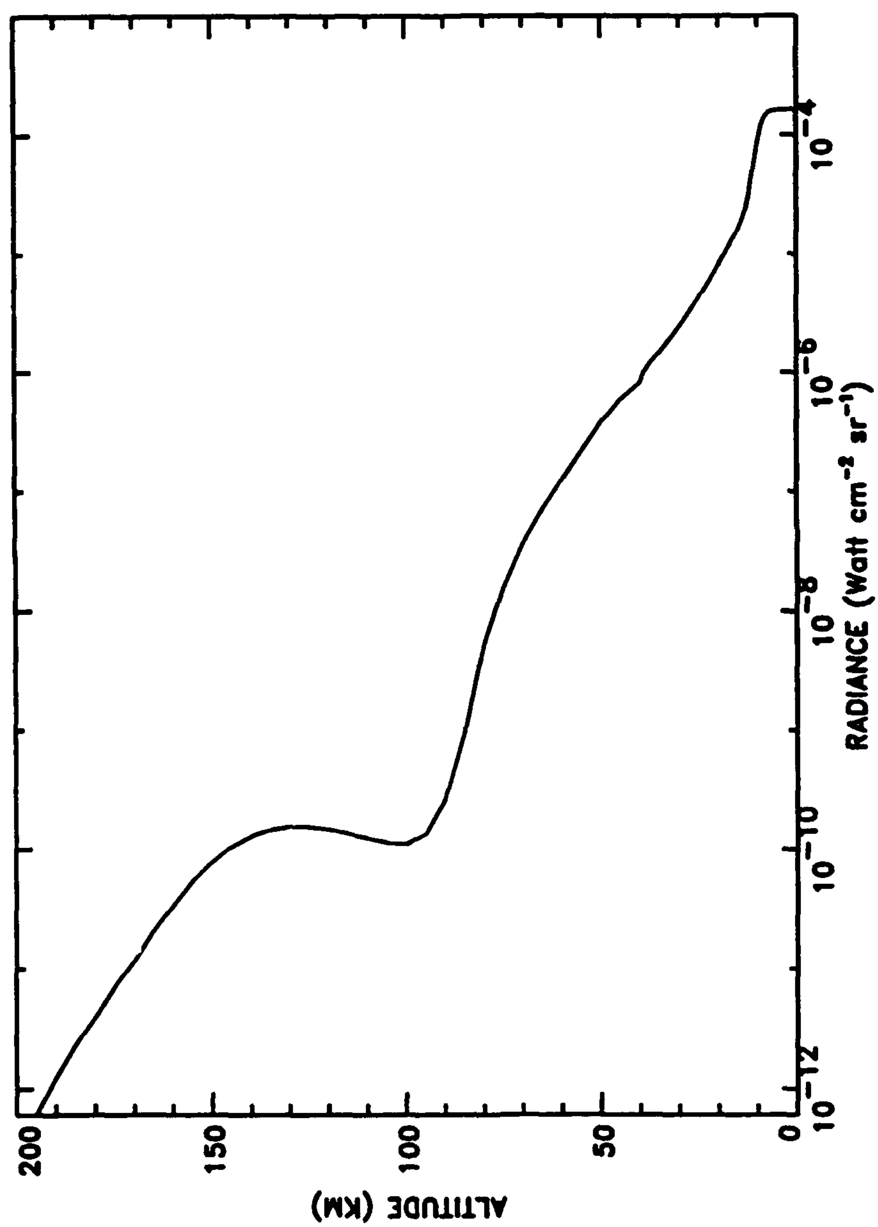


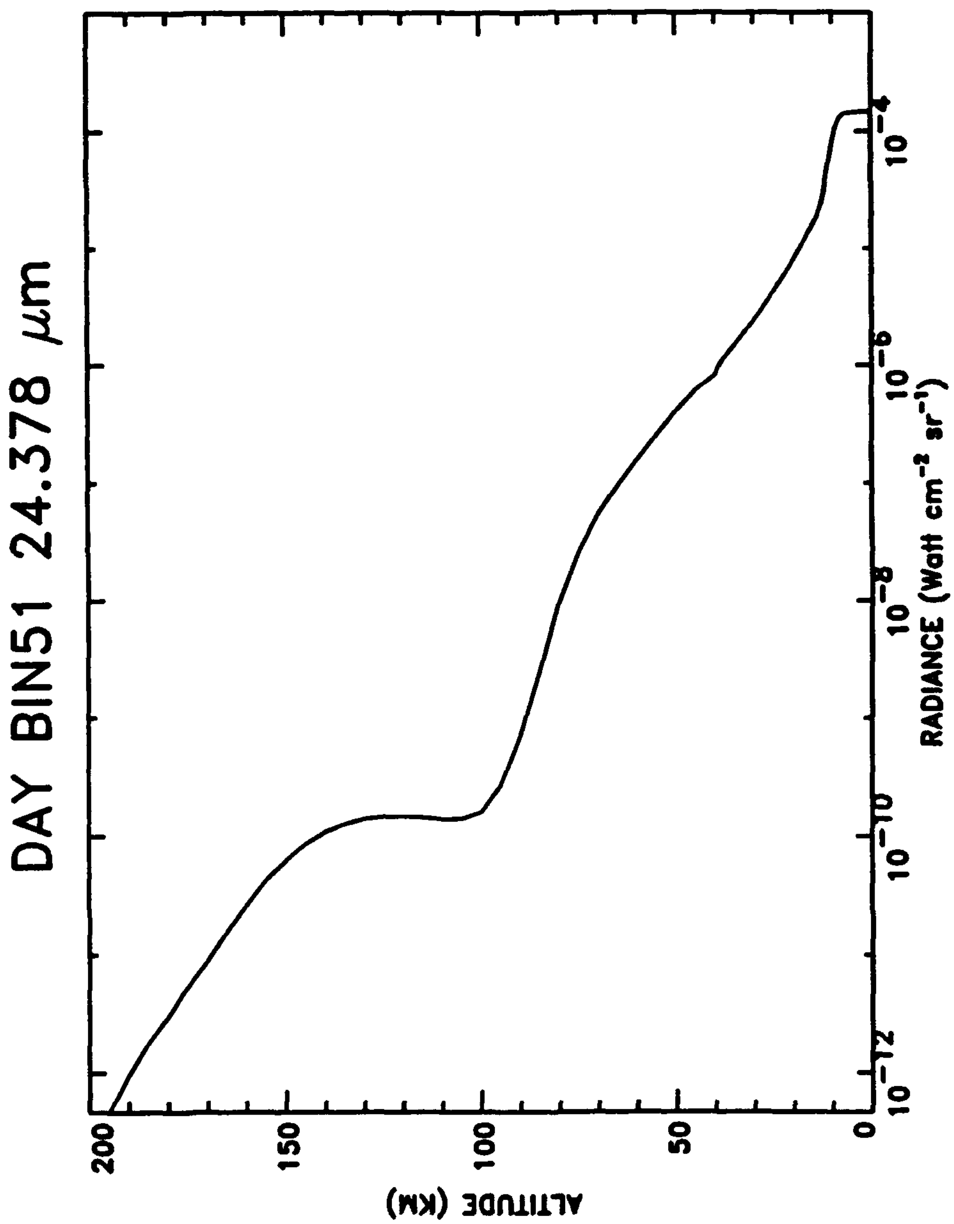


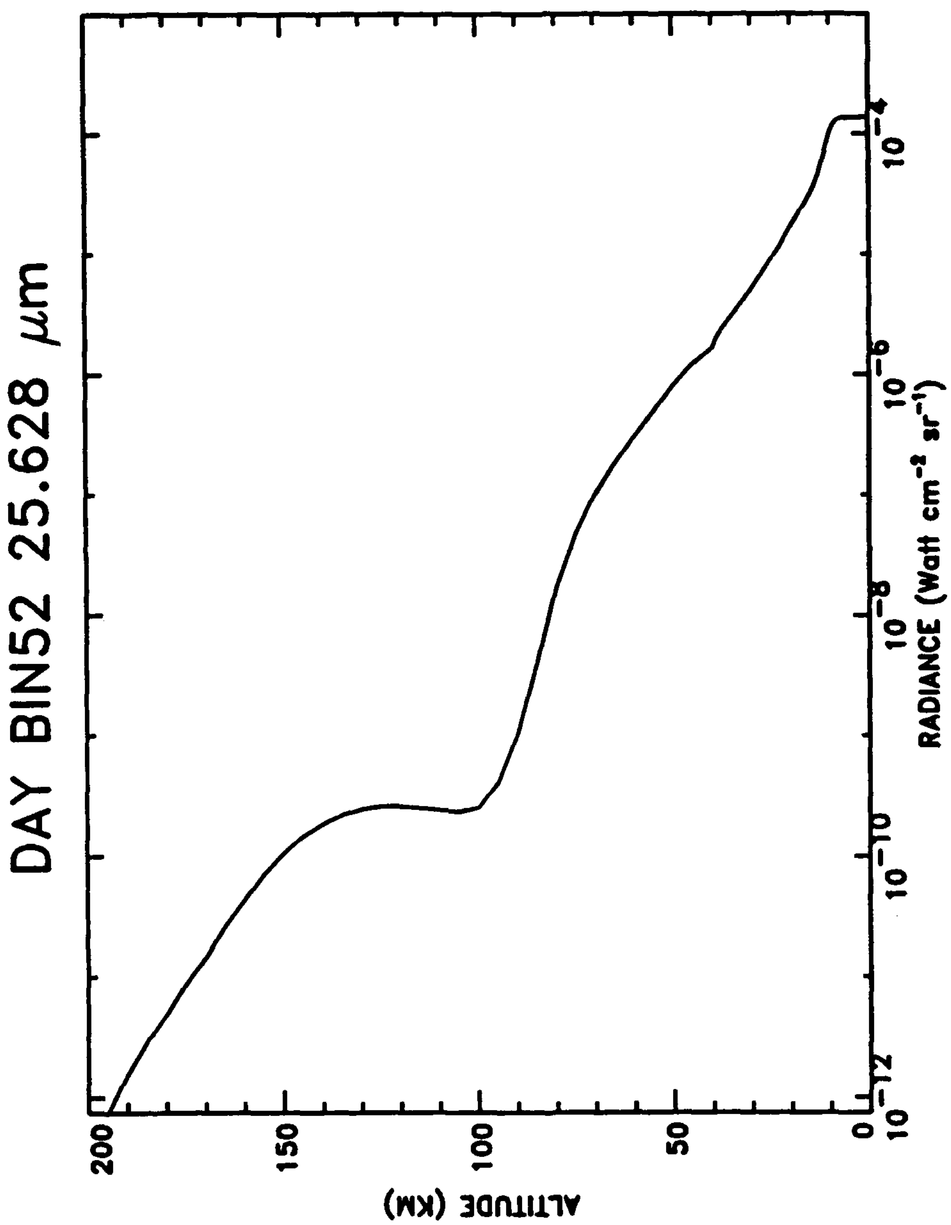
DAY BIN48 20.981 μm
ALTITUDE (KM)
200
150
100
50
0
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴
RADIANCE (Watt cm⁻² sr⁻¹)

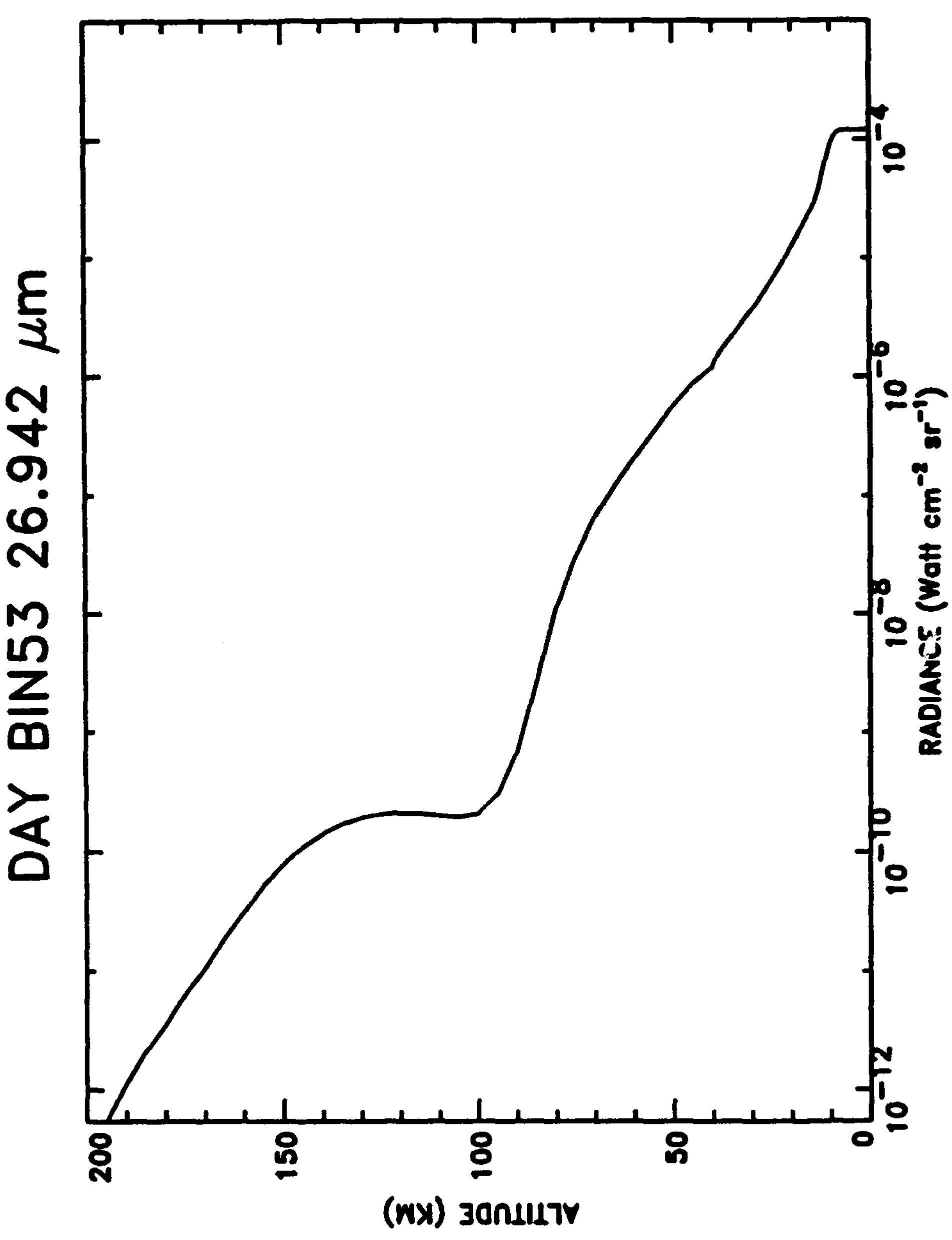

DAY BIN49 22.057 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

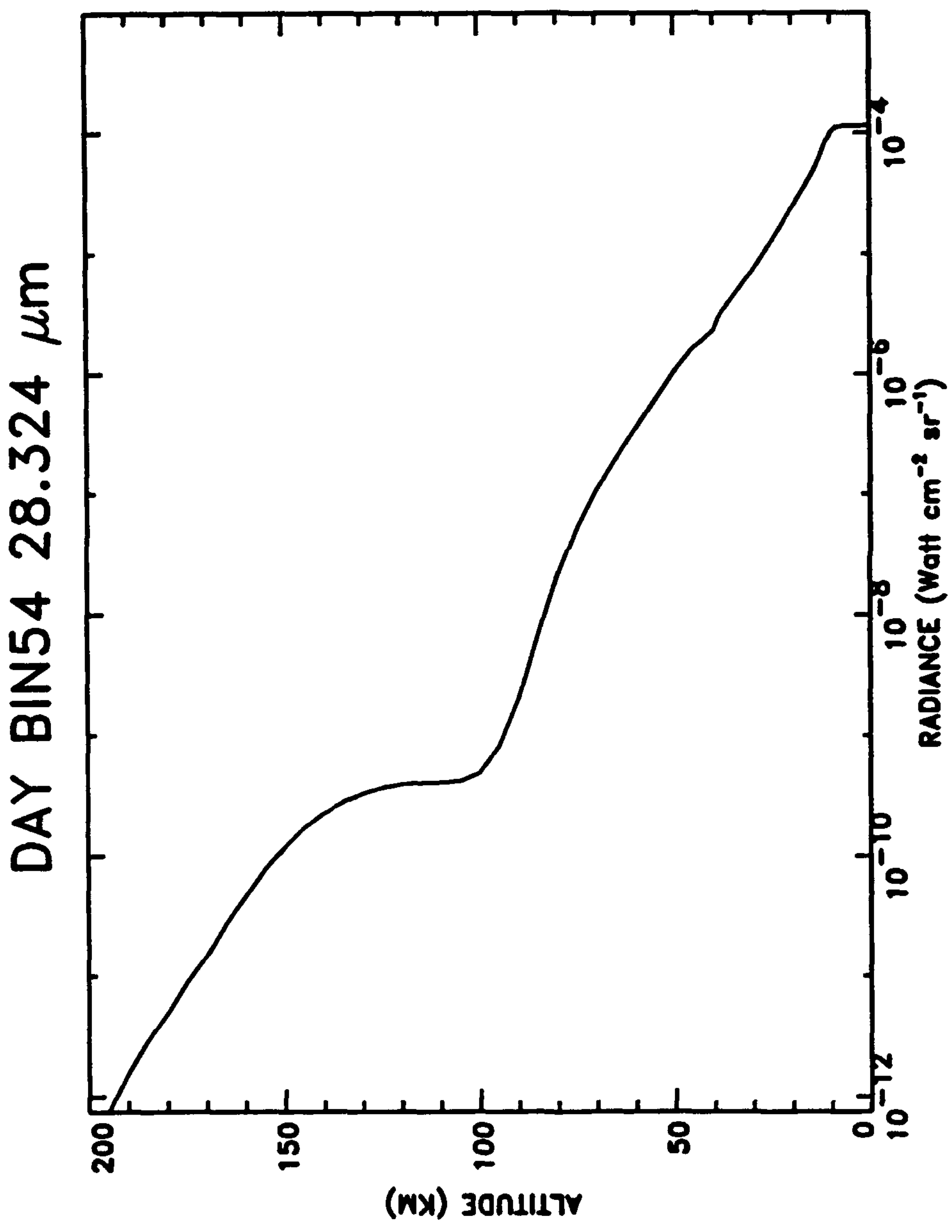
DAY BIN50 23.189 μm



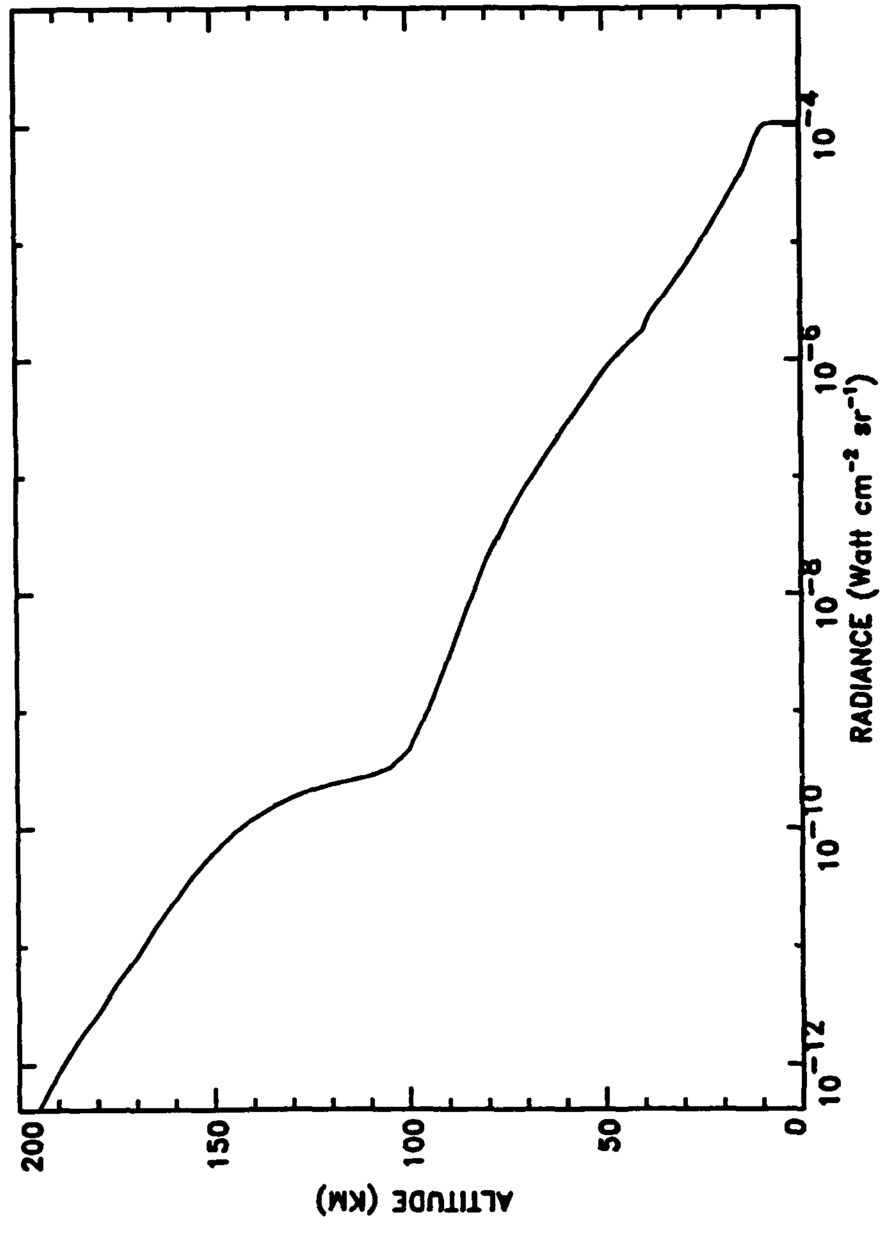

DAY BIN51 24.378 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

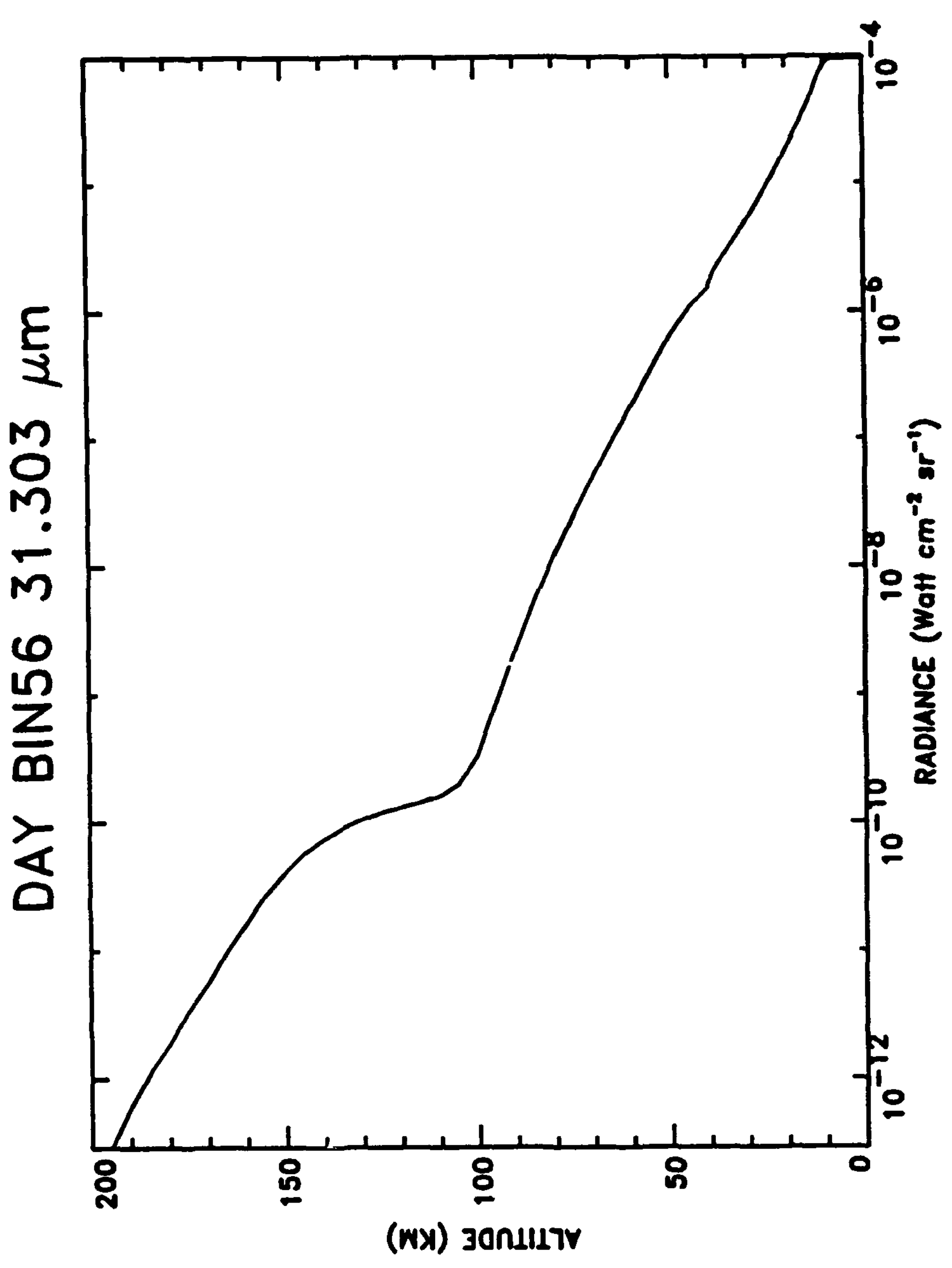

DAY BIN52 25.628 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^-2 sr^-1)
10^-12
10^-10
10^-8
10^-6
10^-4

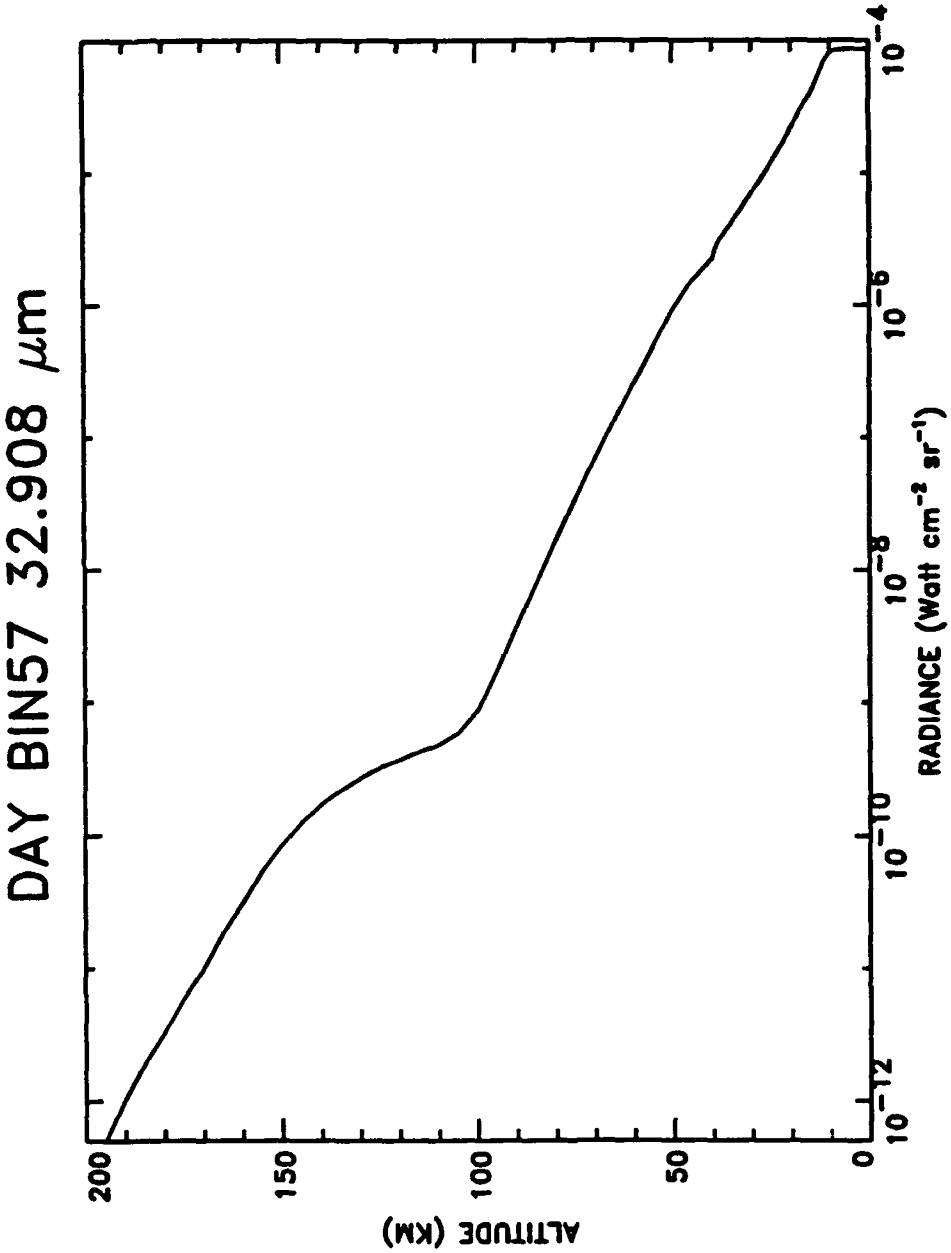

DAY BIN53 26.942 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

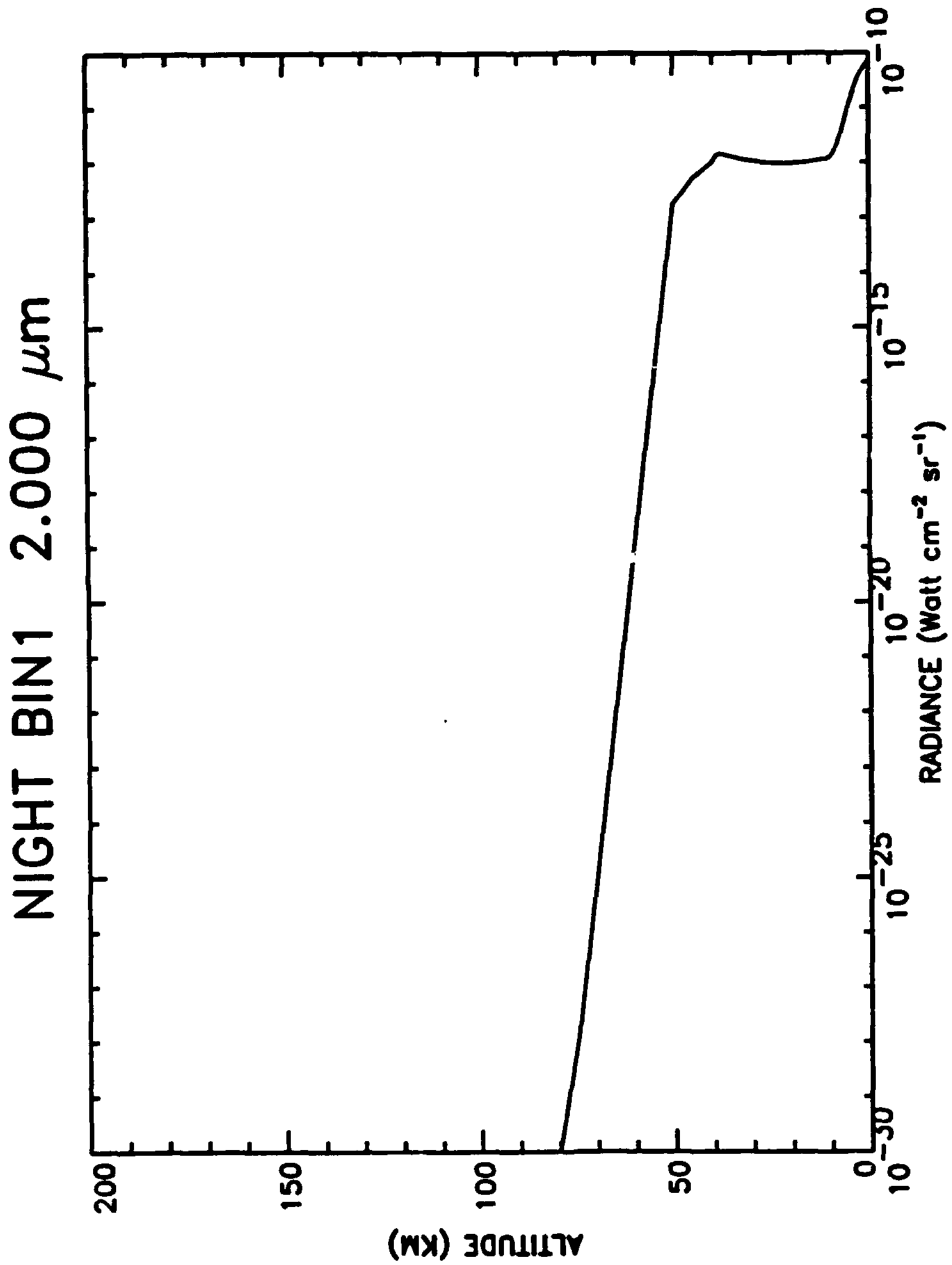

DAY BIN54 28.324 μm
ALTITUDE (KM)
0
50
100
150
200
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}

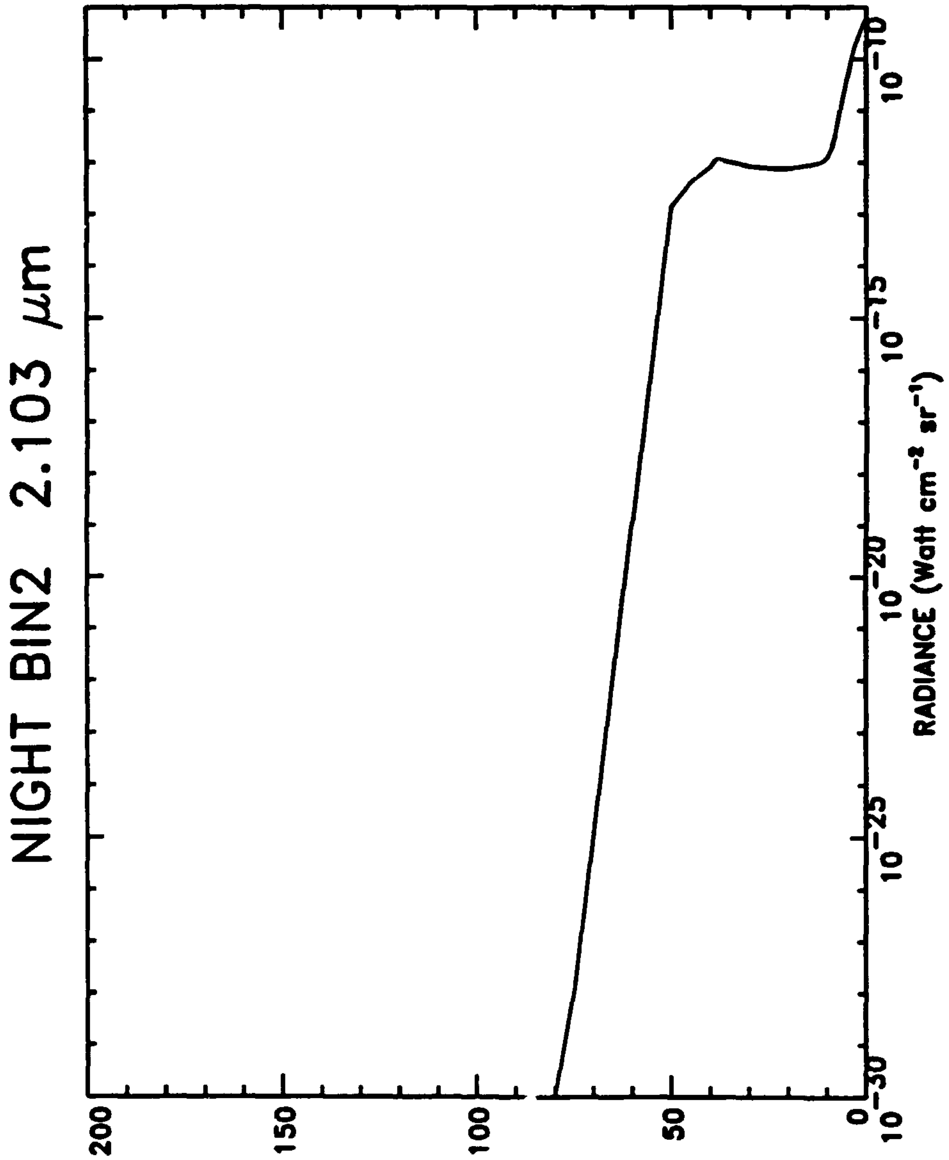
DAY BIN55 29.776 μm

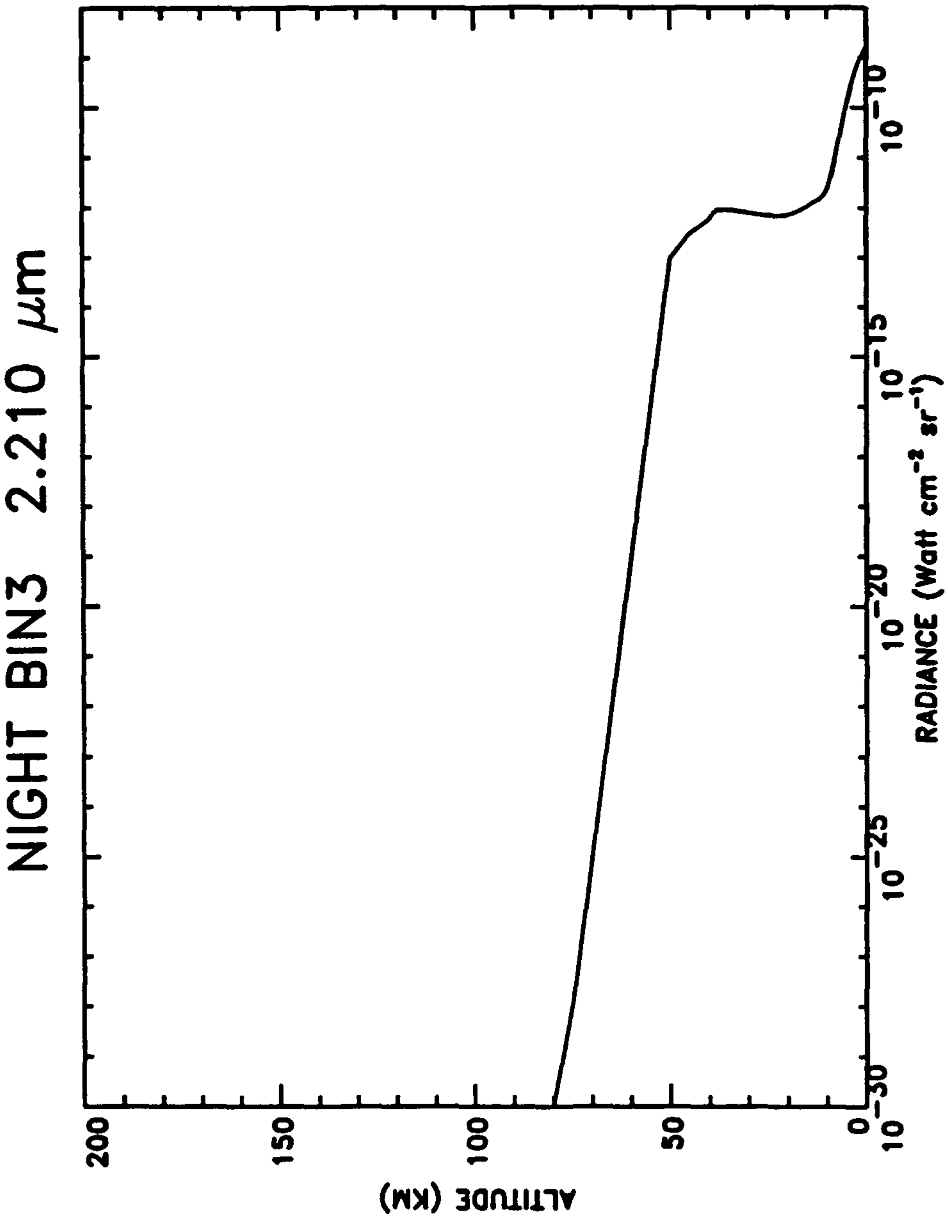



DAY BIN56 31.303 μm
ALTITUDE (KM)
0
50
100
150
200
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}

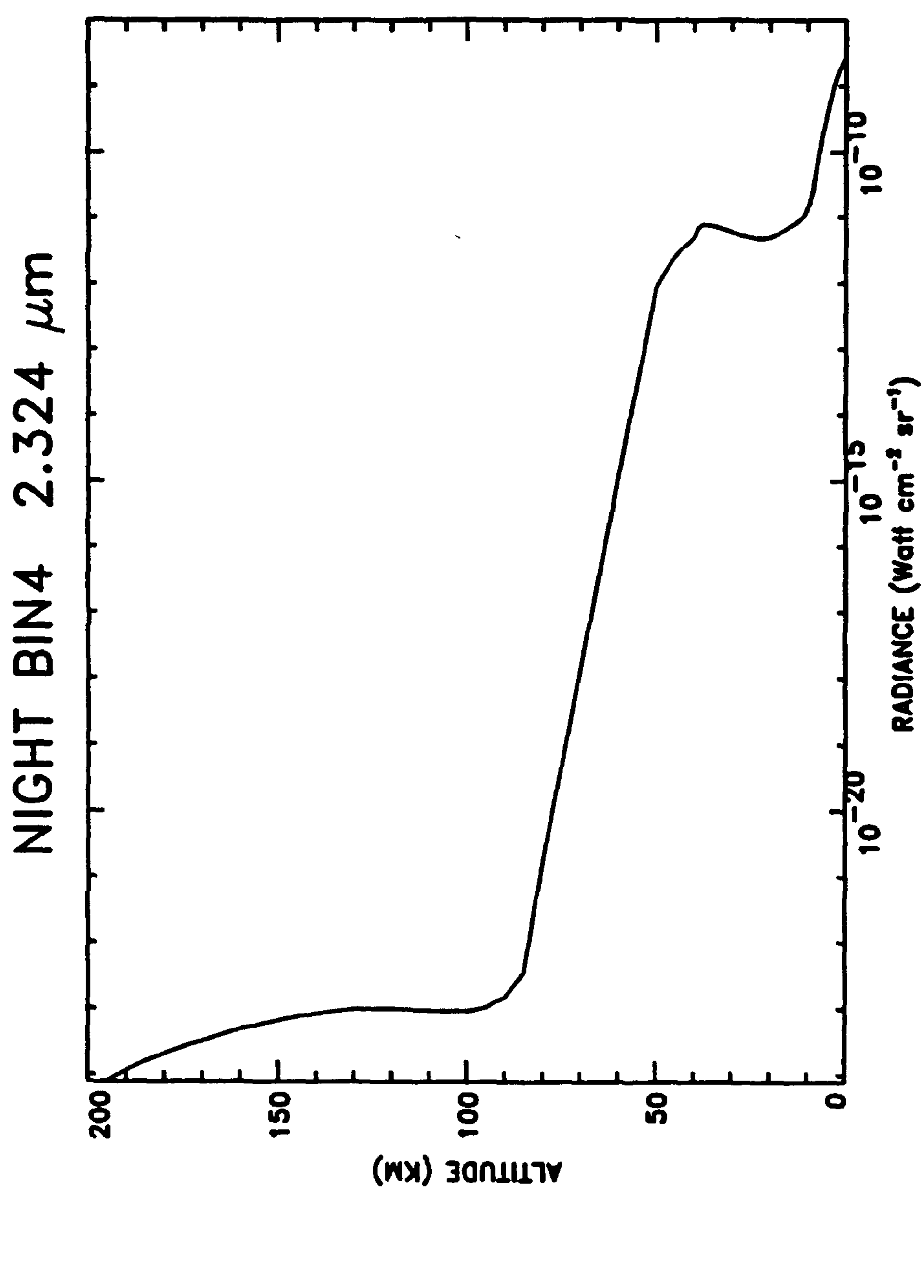

DAY BIN57 32.908 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴


NIGHT BIN1 2.000 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10^−30
10^−25
10^−20
10^−15
10^−10

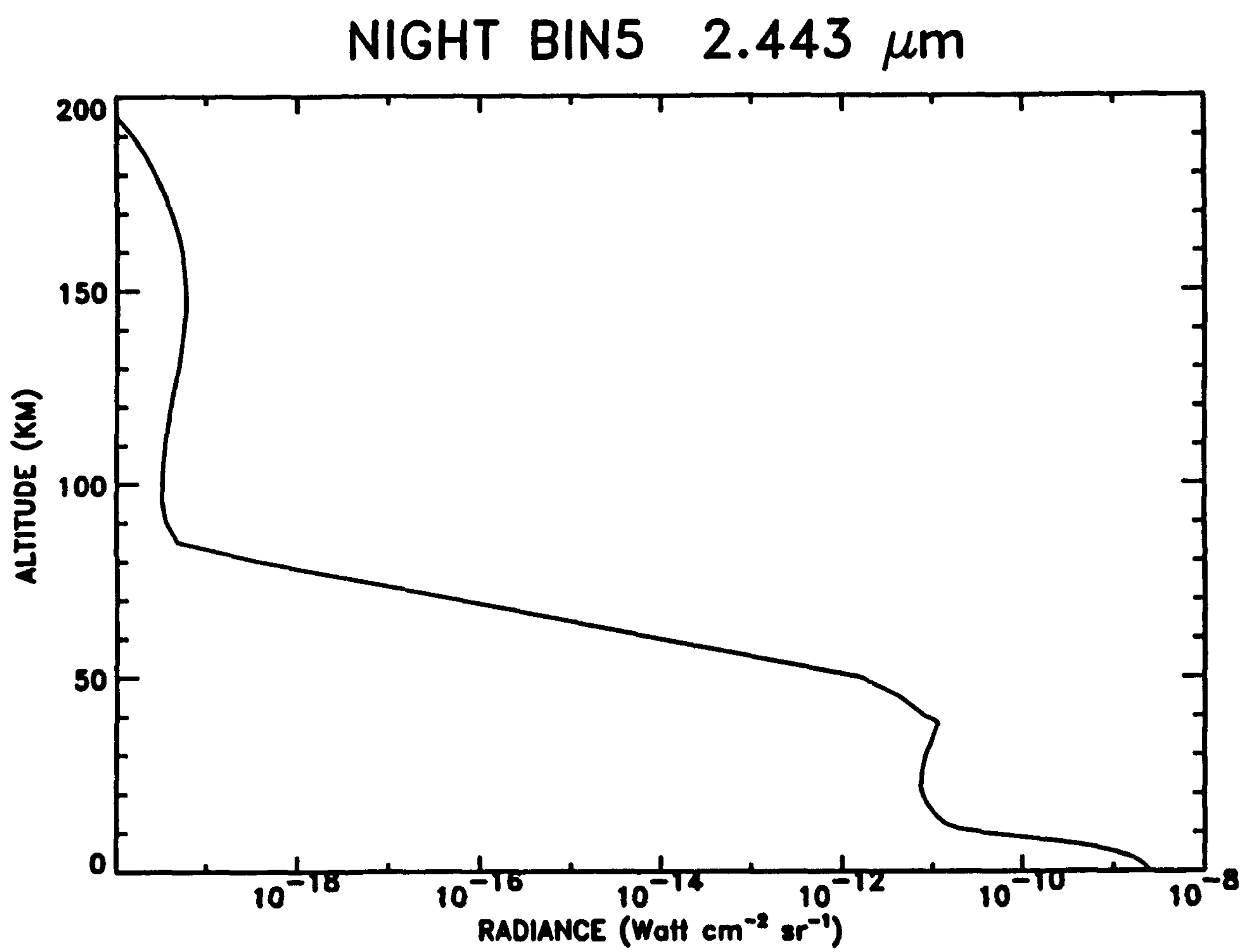

NIGHT BIN2 2.103 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻³⁰
10⁻²⁵
10⁻²⁰
10⁻¹⁵
10⁻¹⁰

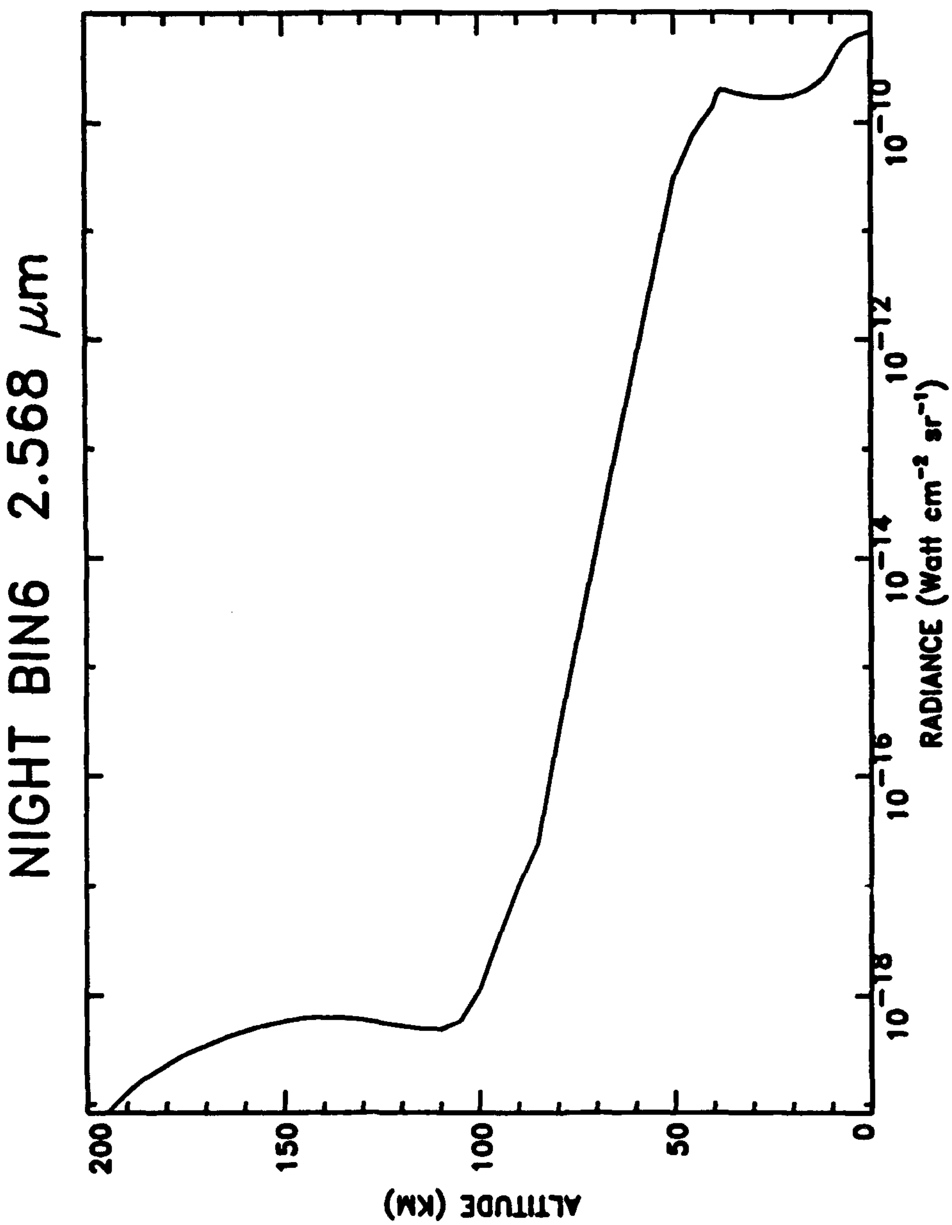


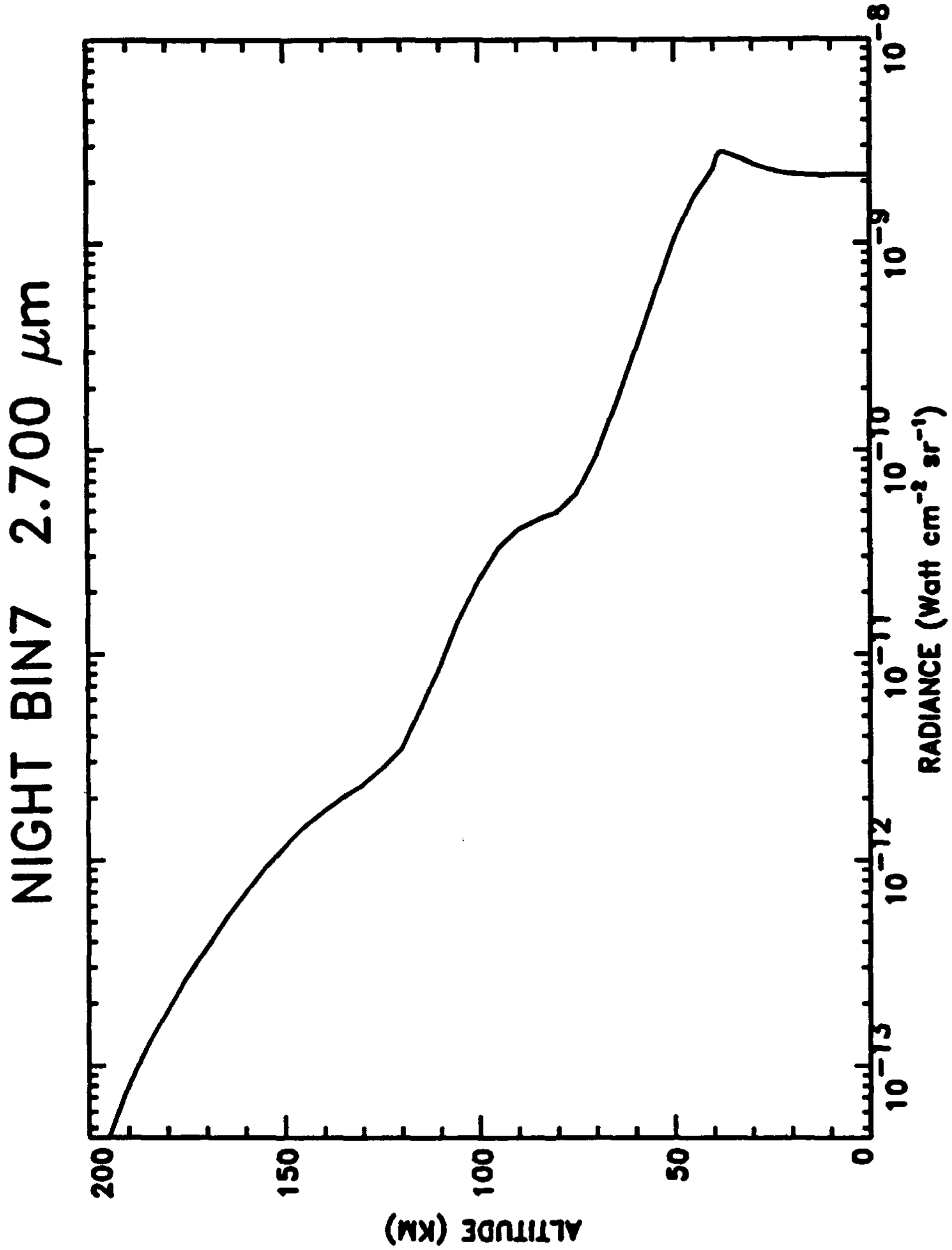
NIGHT BIN3 2.210 μm
ALTITUDE (KM)
0
50
100
150
200
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-30}
10^{-25}
10^{-20}
10^{-15}
10^{-10}

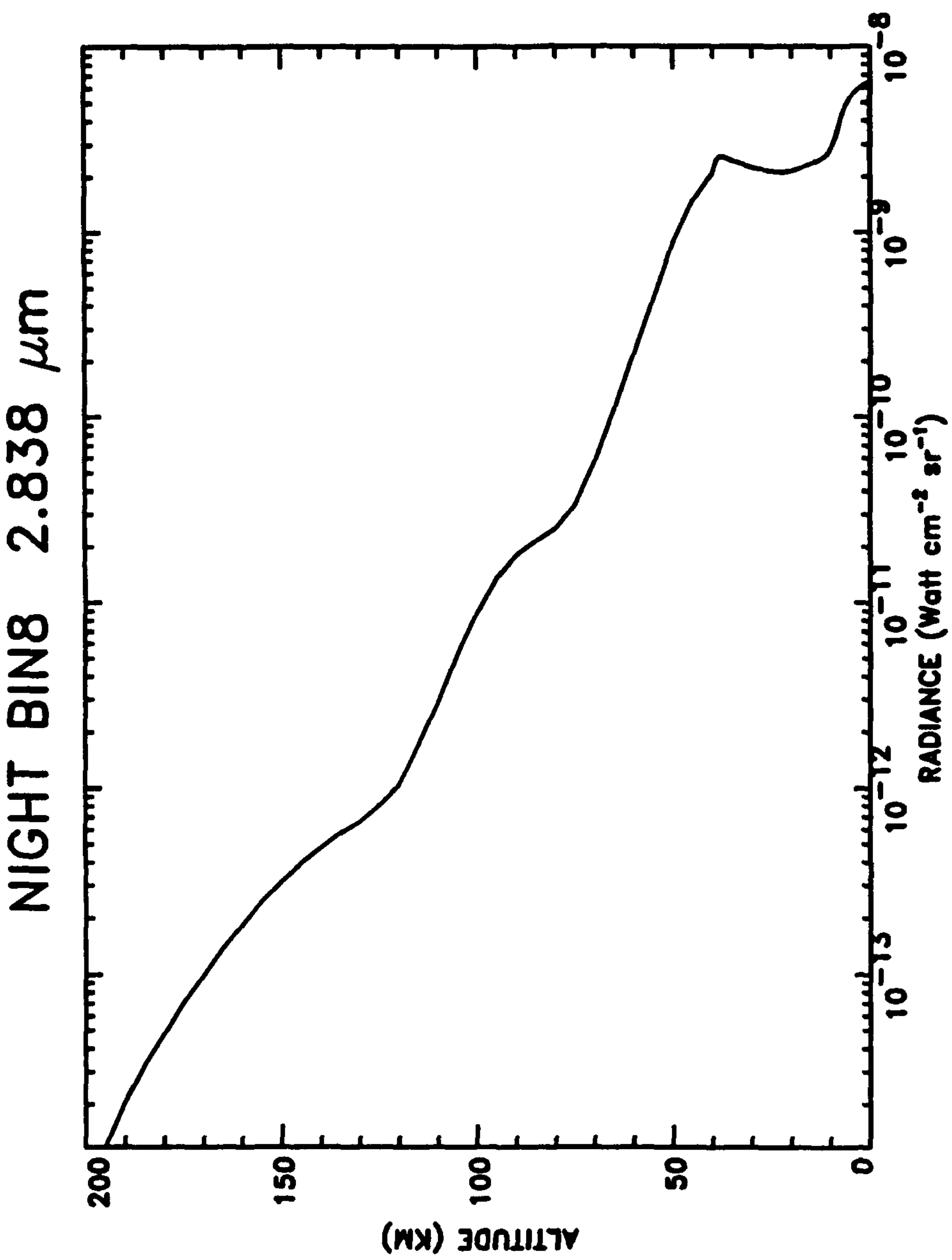


NIGHT BIN4 2.324 μm
ALTITUDE (KM)
RADIANCE (Watt cm^{-2} sr^{-1})
200
150
100
50
0
10^{-20}
10^{-15}
10^{-10}


NIGHT BIN5 2.443 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁸
10⁻¹⁶
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸

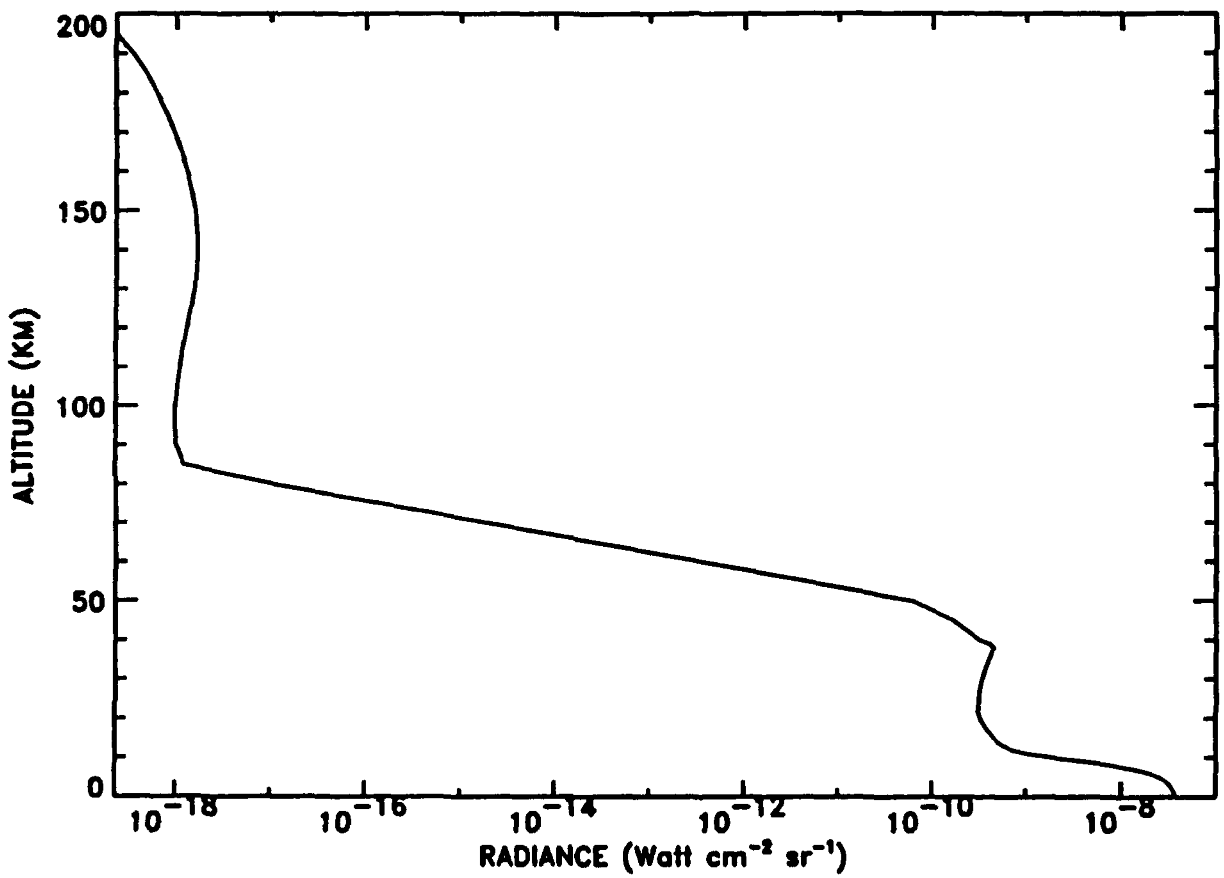

NIGHT BIN6 2.568 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁸
10⁻¹⁶
10⁻¹⁴
10⁻¹²
10⁻¹⁰

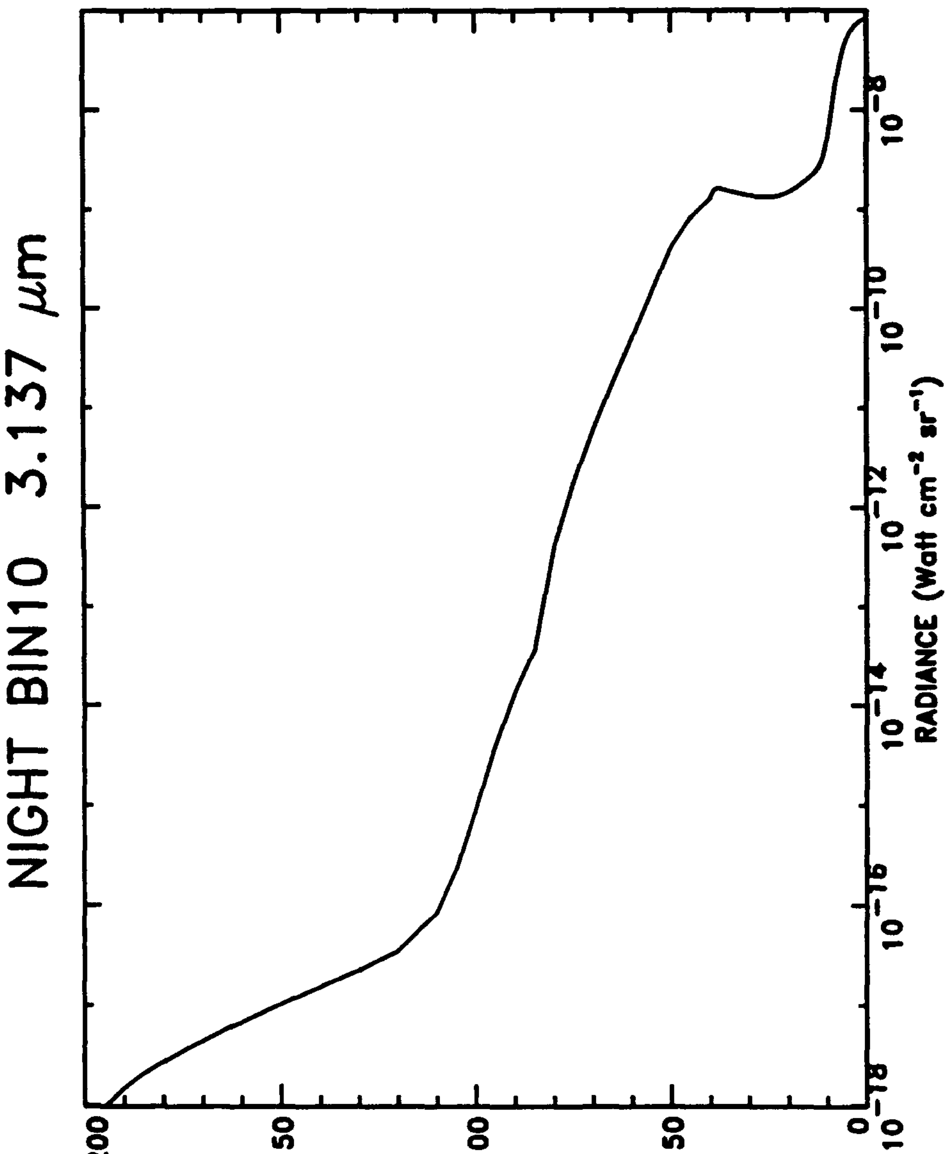

NIGHT BIN7 2.700 μm
ALTITUDE (KM)
RADIANCE (Watt cm^{-2} sr^{-1})
200
150
100
50
0
10^{-13}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}

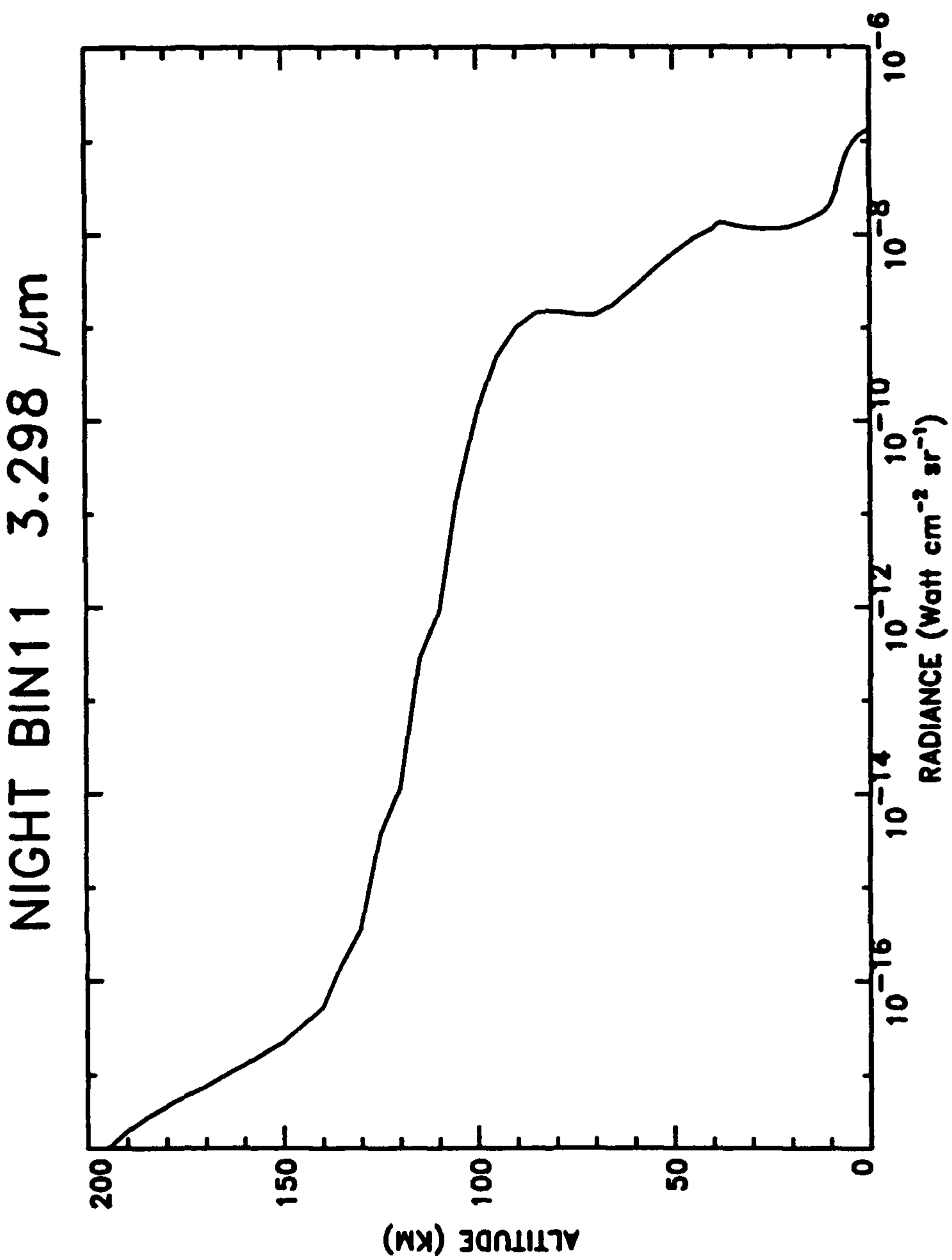


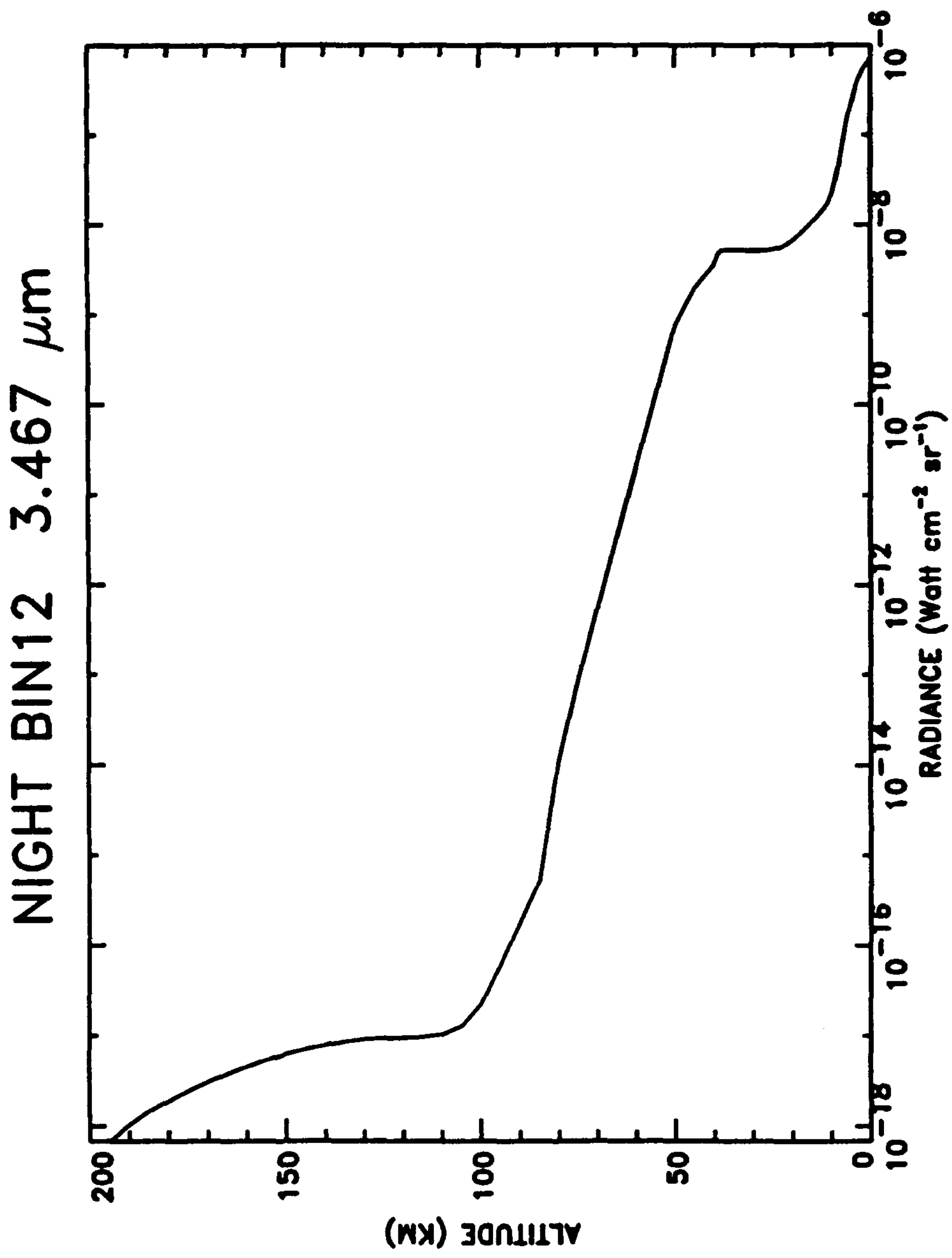
NIGHT BIN8 2.838 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹³
10⁻¹²
10⁻¹¹
10⁻¹⁰
10⁻⁹
10⁻⁸

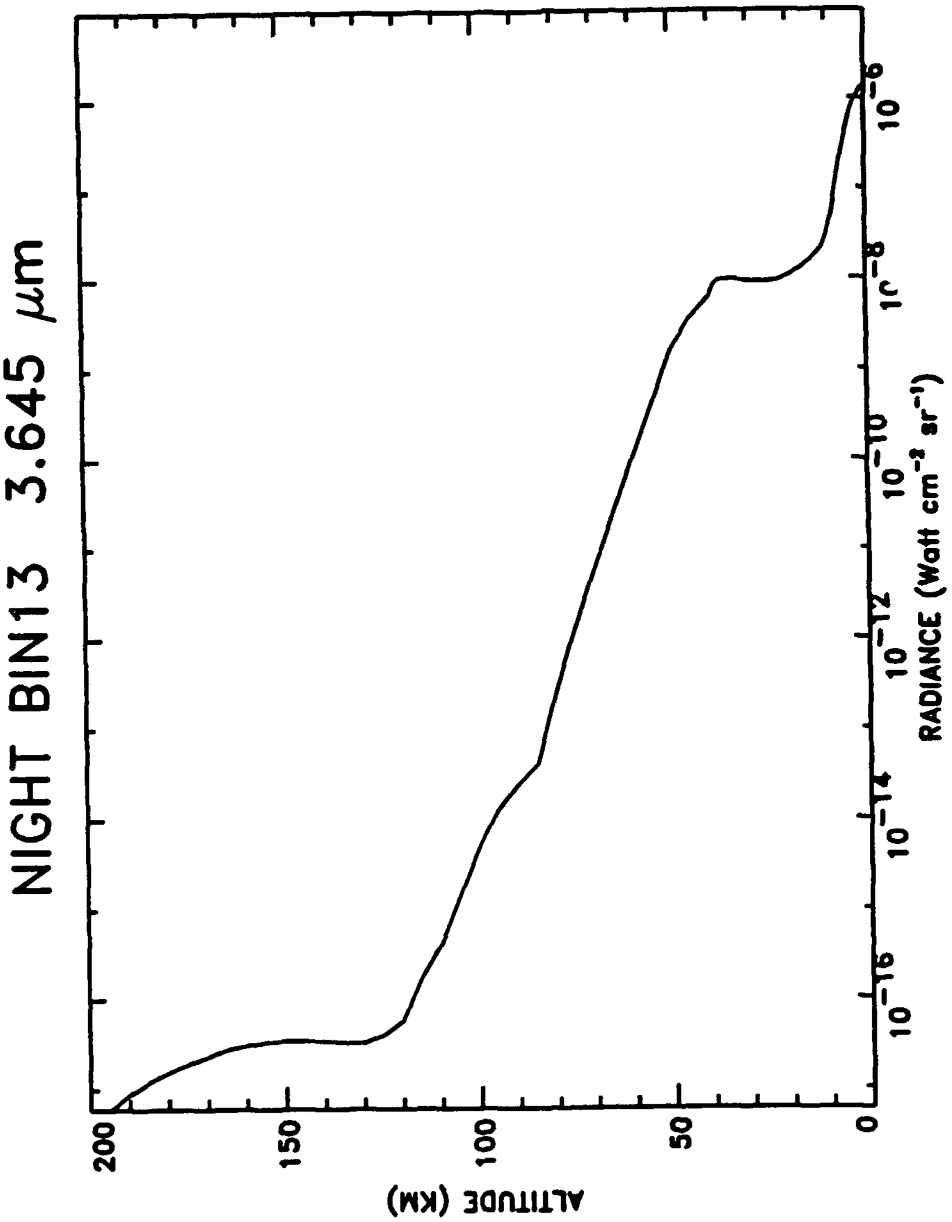
NIGHT BIN9 2.984 μm



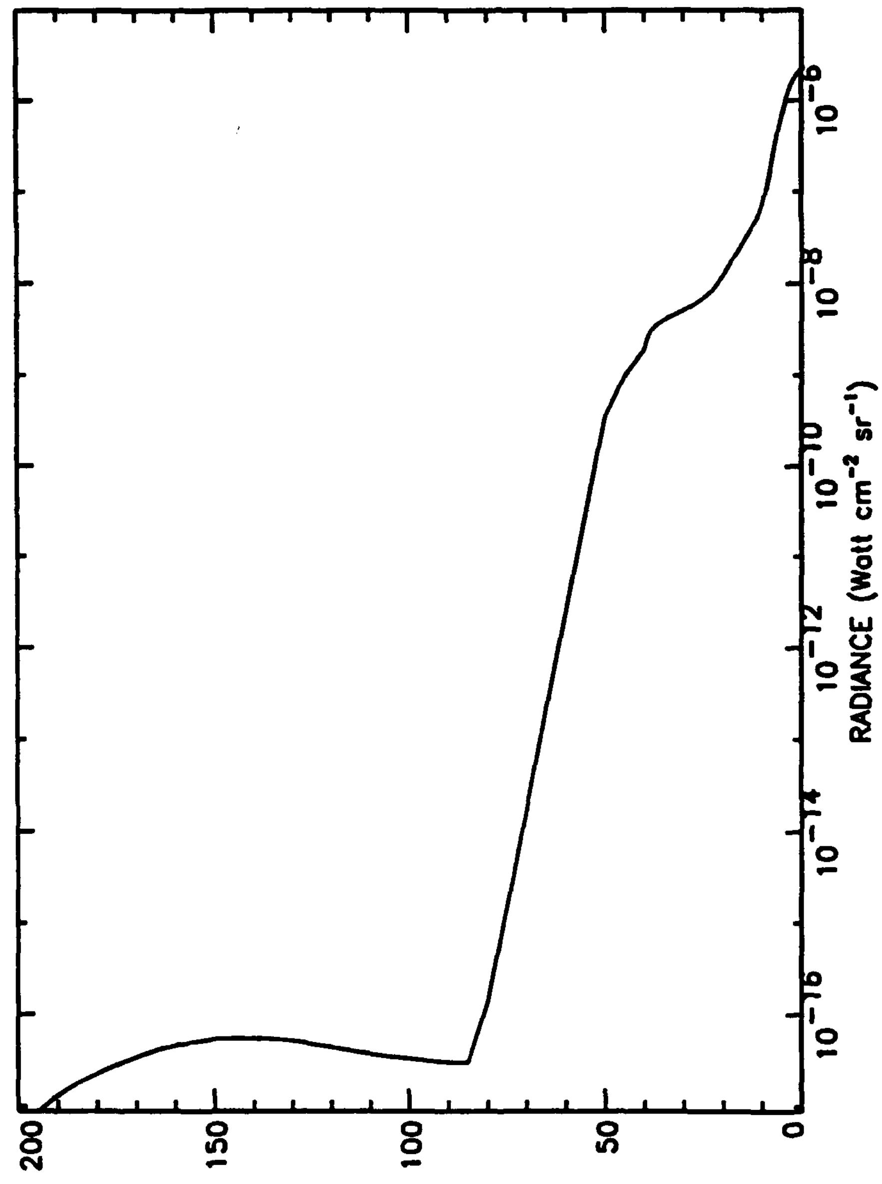

NIGHT BIN10 3.137 μm
ALTITUDE (KM)
RADIANCE (Watt cm⁻² sr⁻¹)
200
150
100
50
0
10⁻¹⁸
10⁻¹⁶
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸

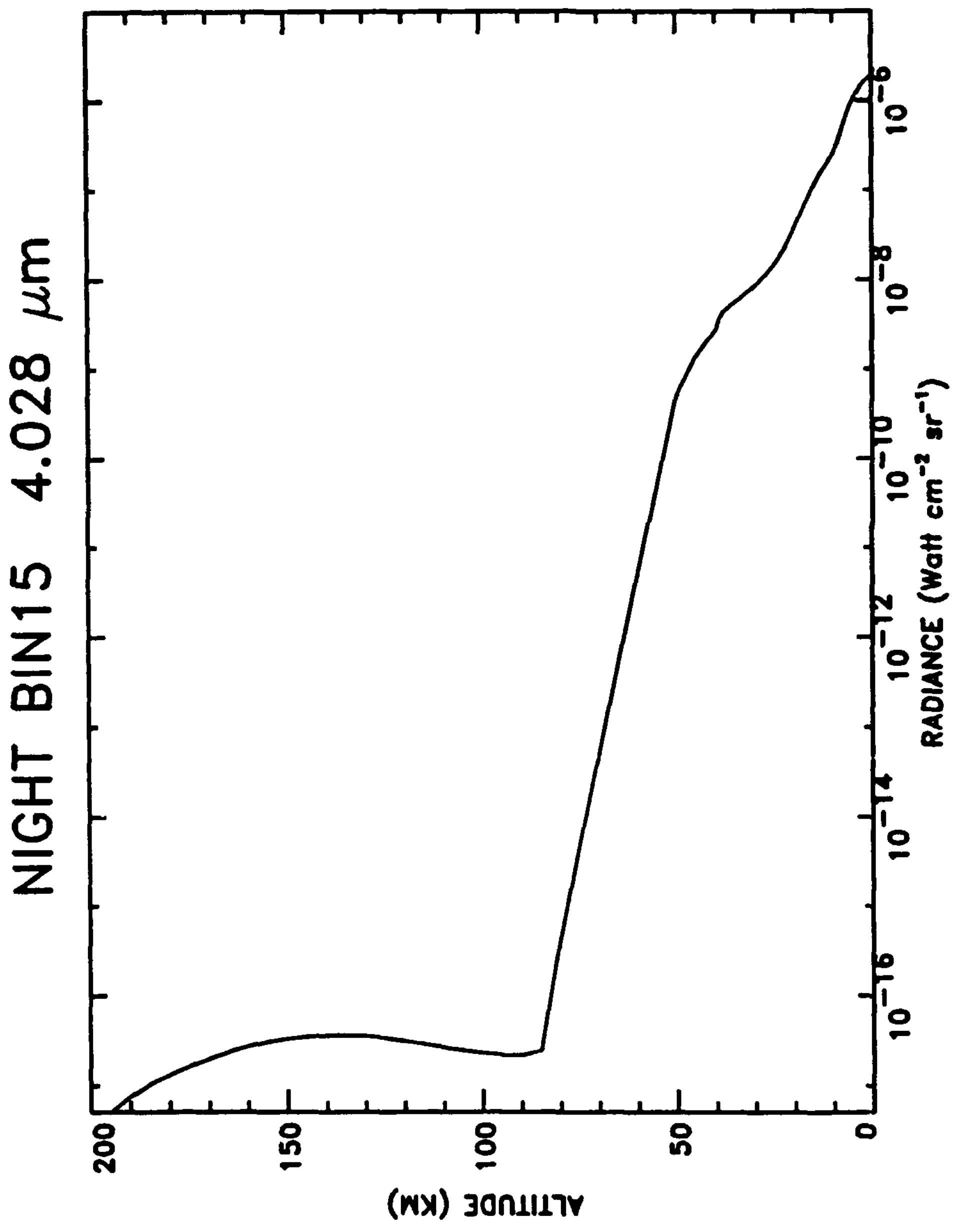

NIGHT BIN11 3.298 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁶
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶


NIGHT BIN12 3.467 μm
ALTITUDE (KM)
200
150
100
50
0
10^-18
10^-16
10^-14
10^-12
10^-10
10^-8
10^-6
RADIANCE (Watt cm^-2 sr^-1)

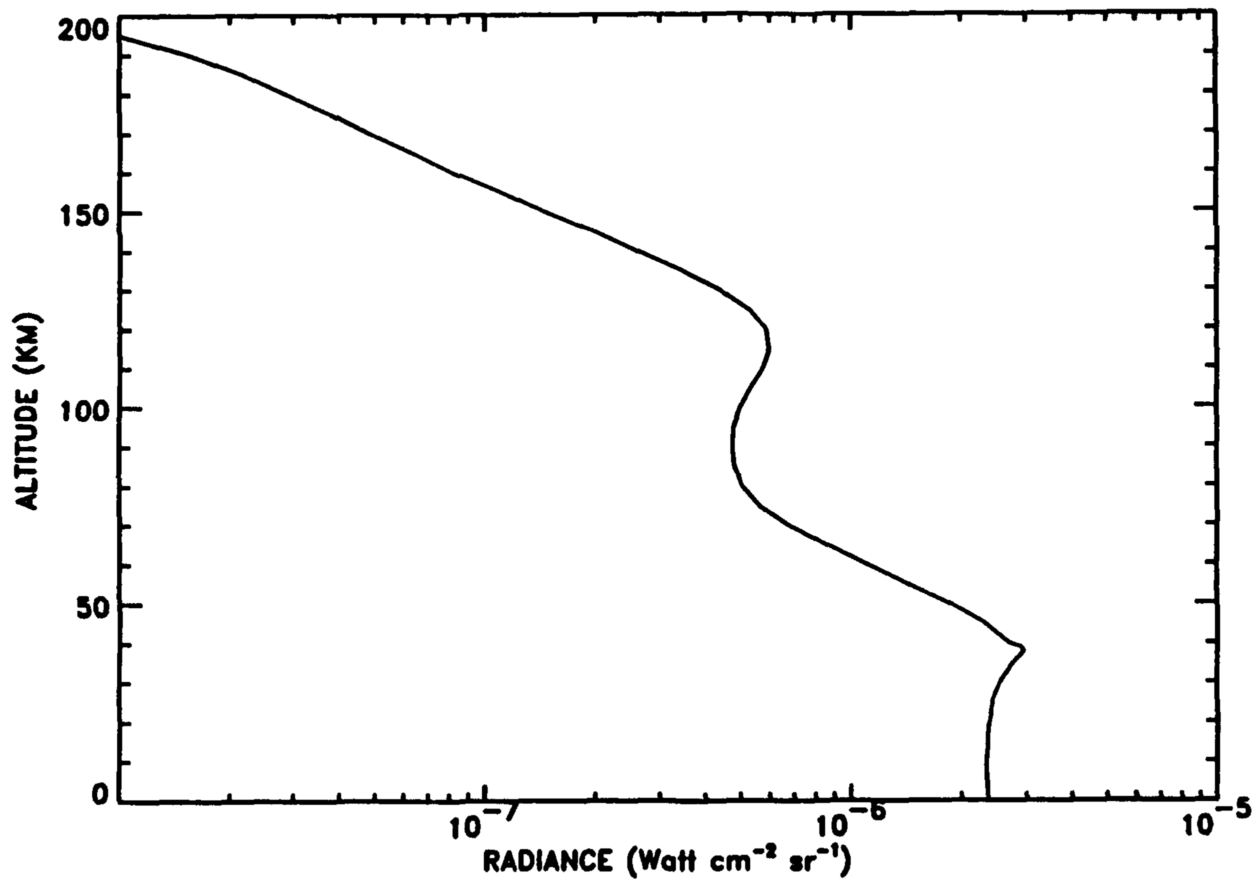

NIGHT BIN13 3.645 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^-2 sr^-1)
10^-16
10^-14
10^-12
10^-10
10^-8
10^-6

NIGHT BIN14 3.832 μm

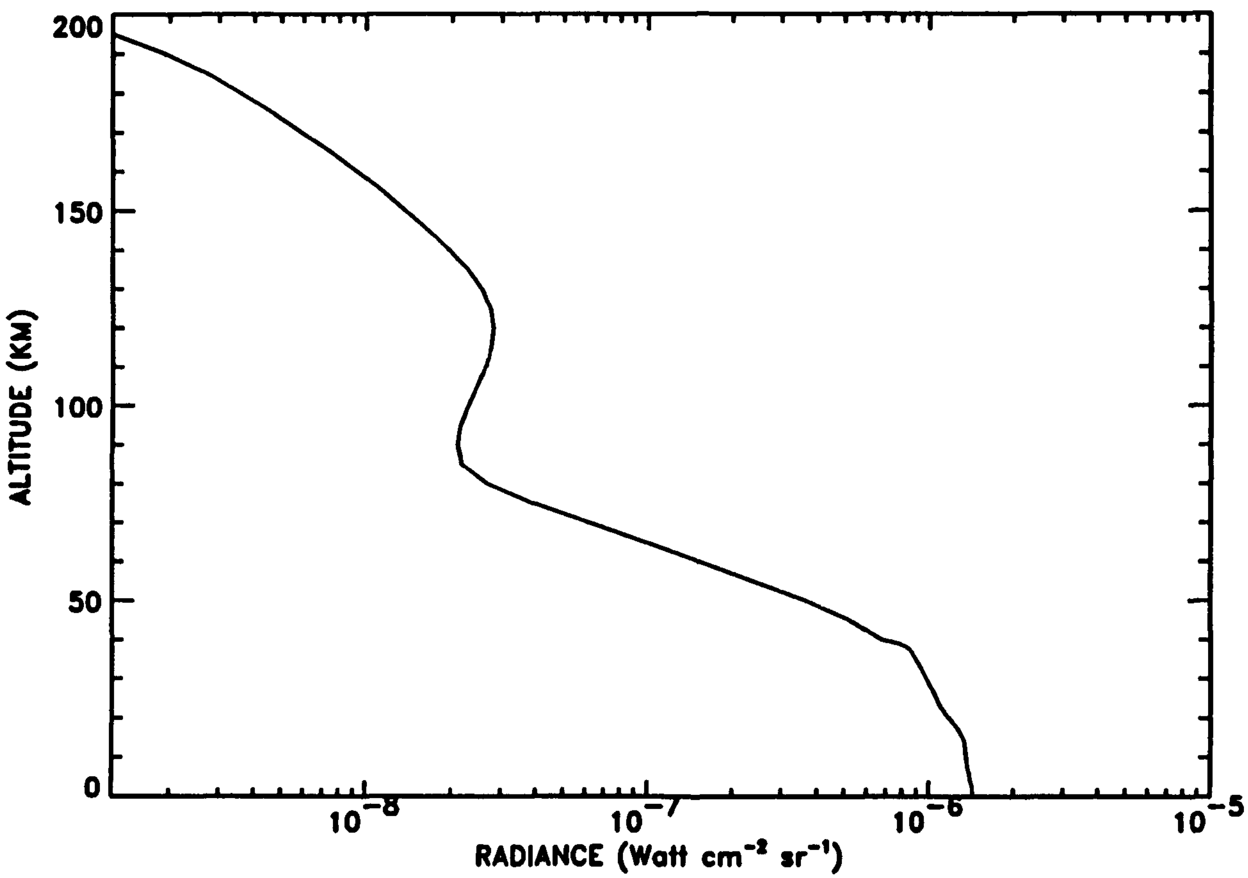


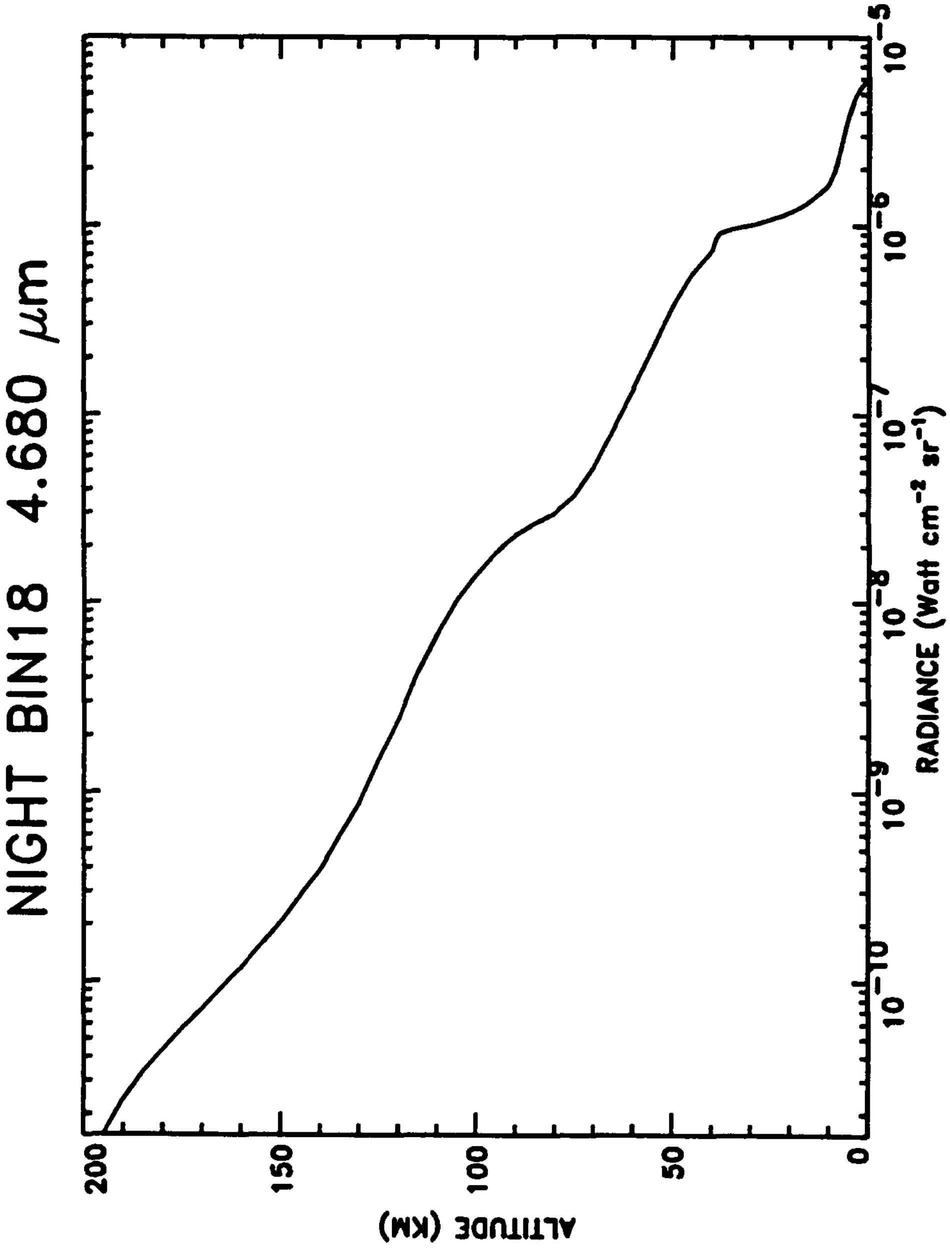

NIGHT BIN15 4.028 μm
RADIANCE (Watt cm⁻² sr⁻¹)
ALTITUDE (KM)
0
50
100
150
200
10⁻¹⁶
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶

NIGHT BIN16 4.235 μm

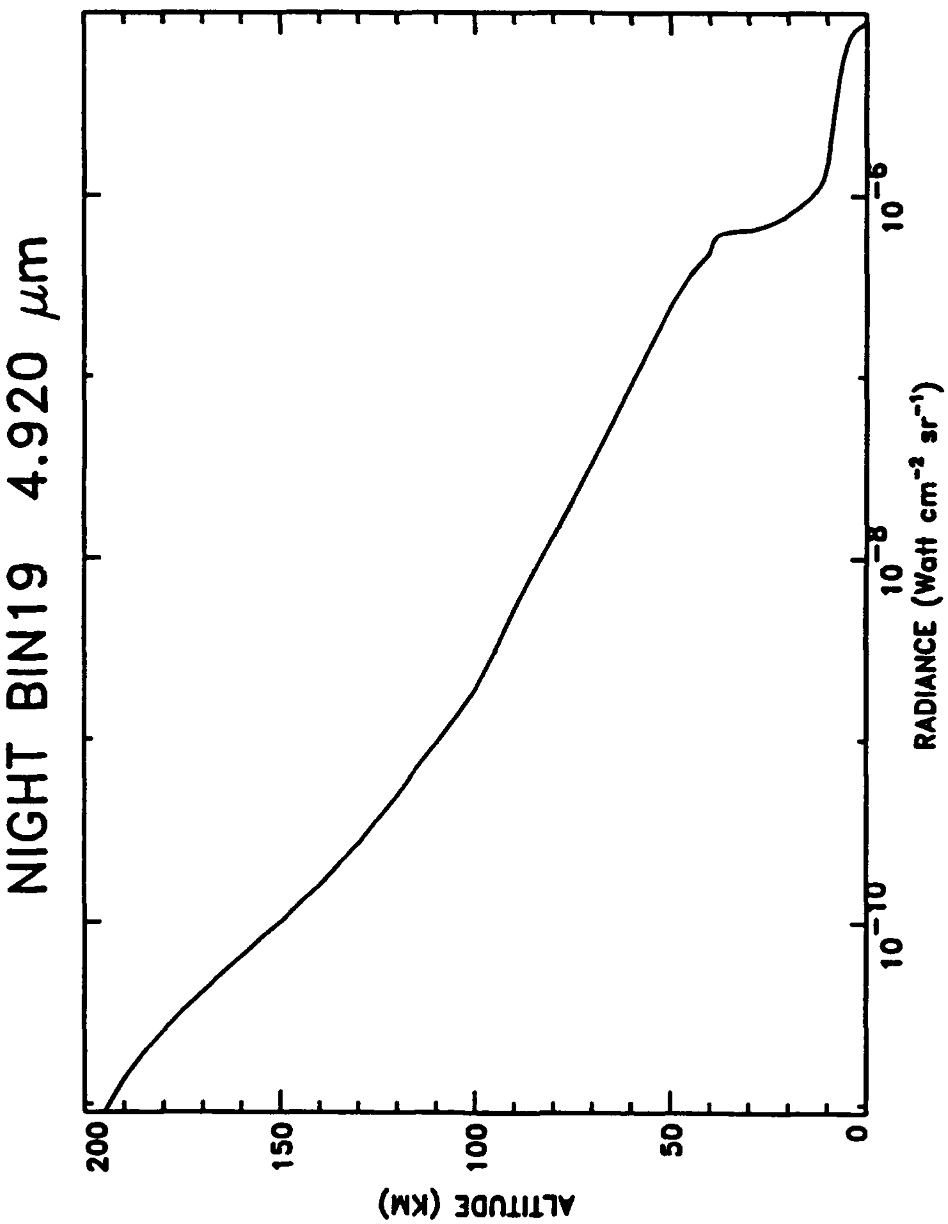


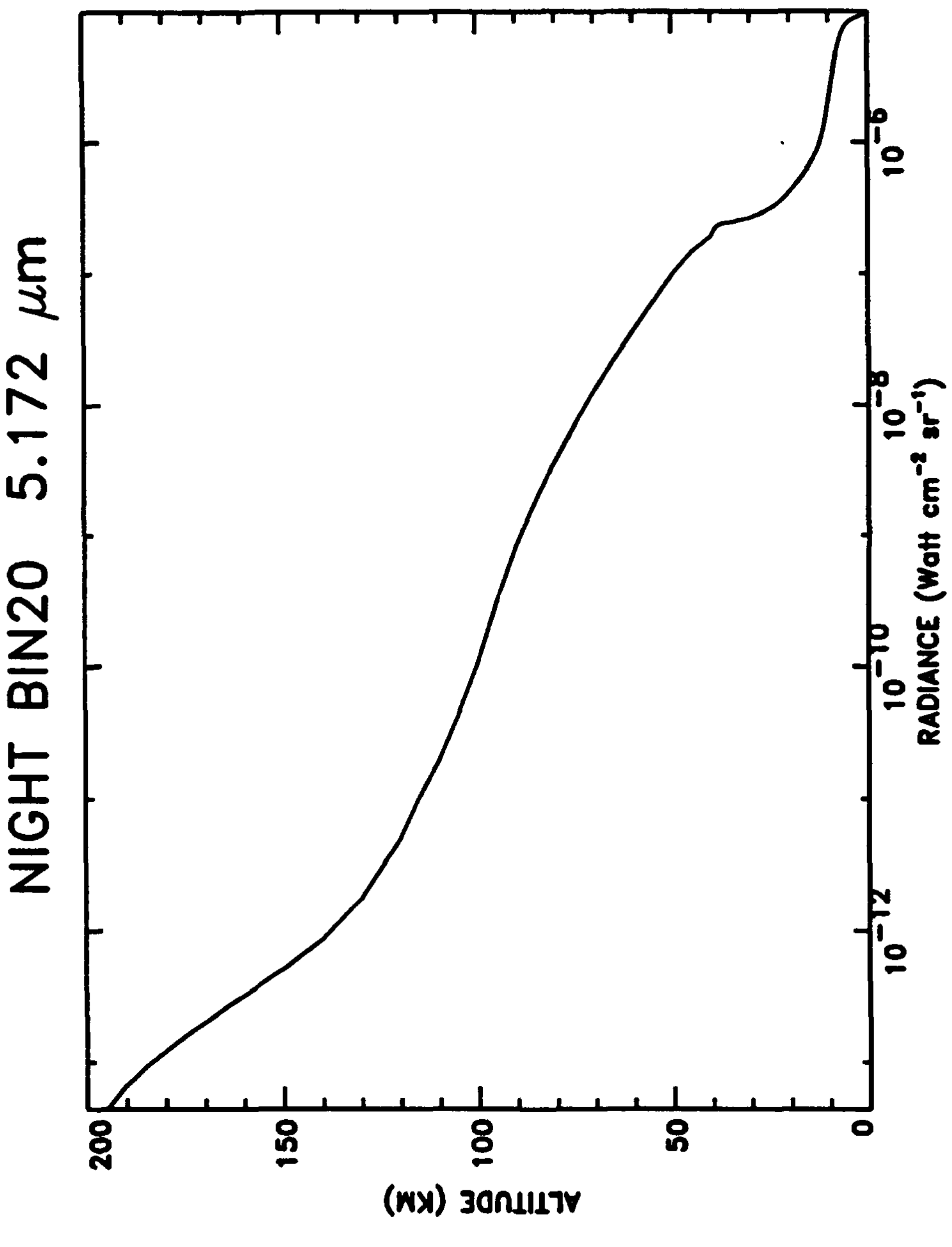
NIGHT BIN17 4.452 μm



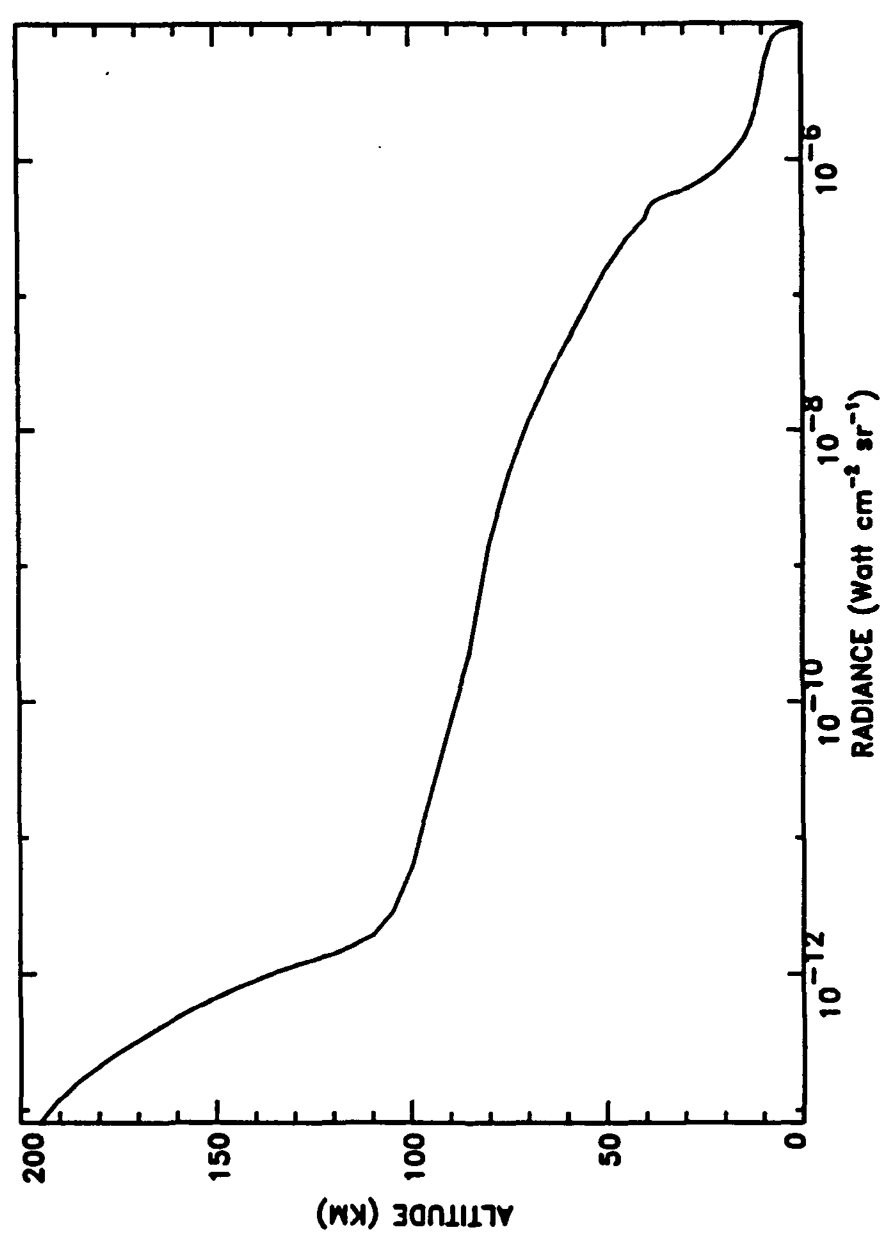


NIGHT BIN18 4.680 μm
ALTITUDE (KM)
200
150
100
50
0
10^-10
10^-9
10^-8
10^-7
10^-6
10^-5
RADIANCE (Watt cm^-2 sr^-1)

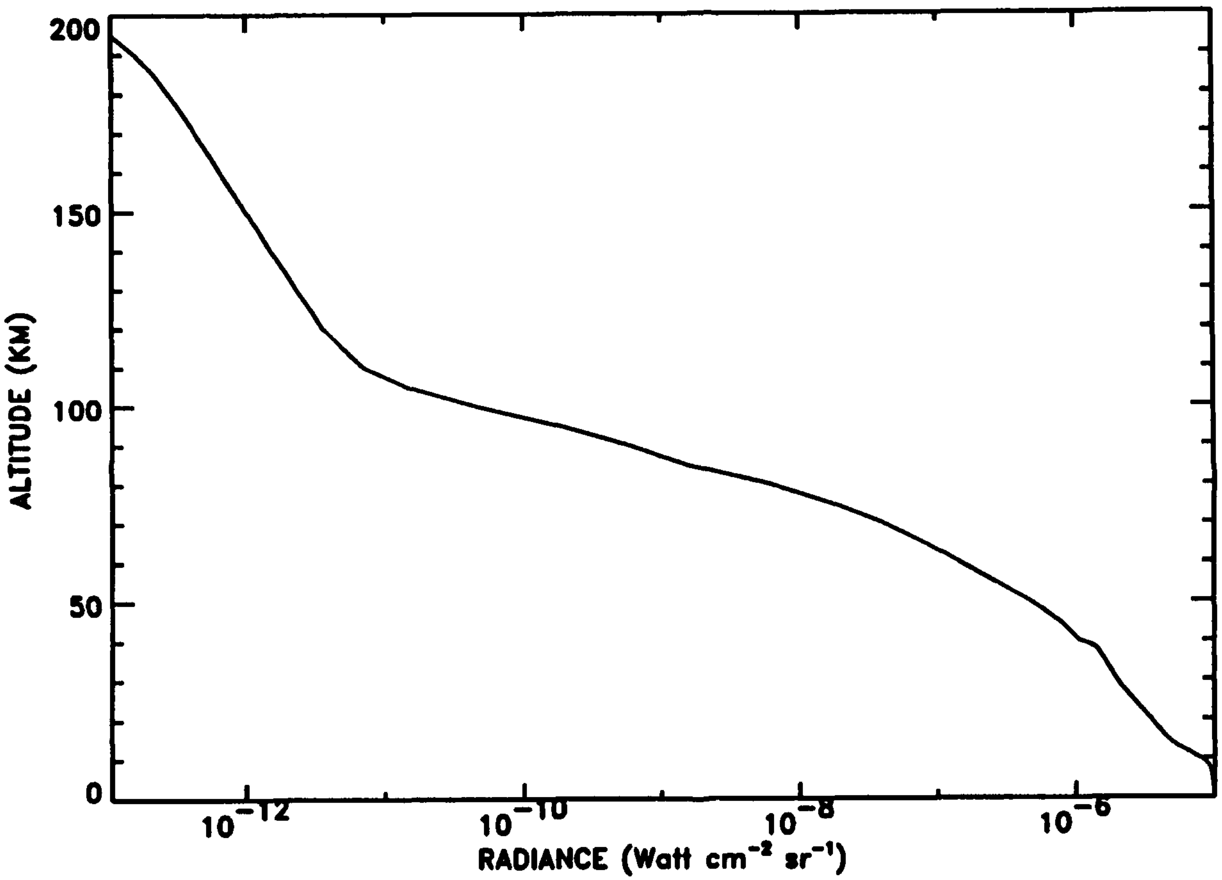

NIGHT BIN19 4.920 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁰
10⁻⁸
10⁻⁶

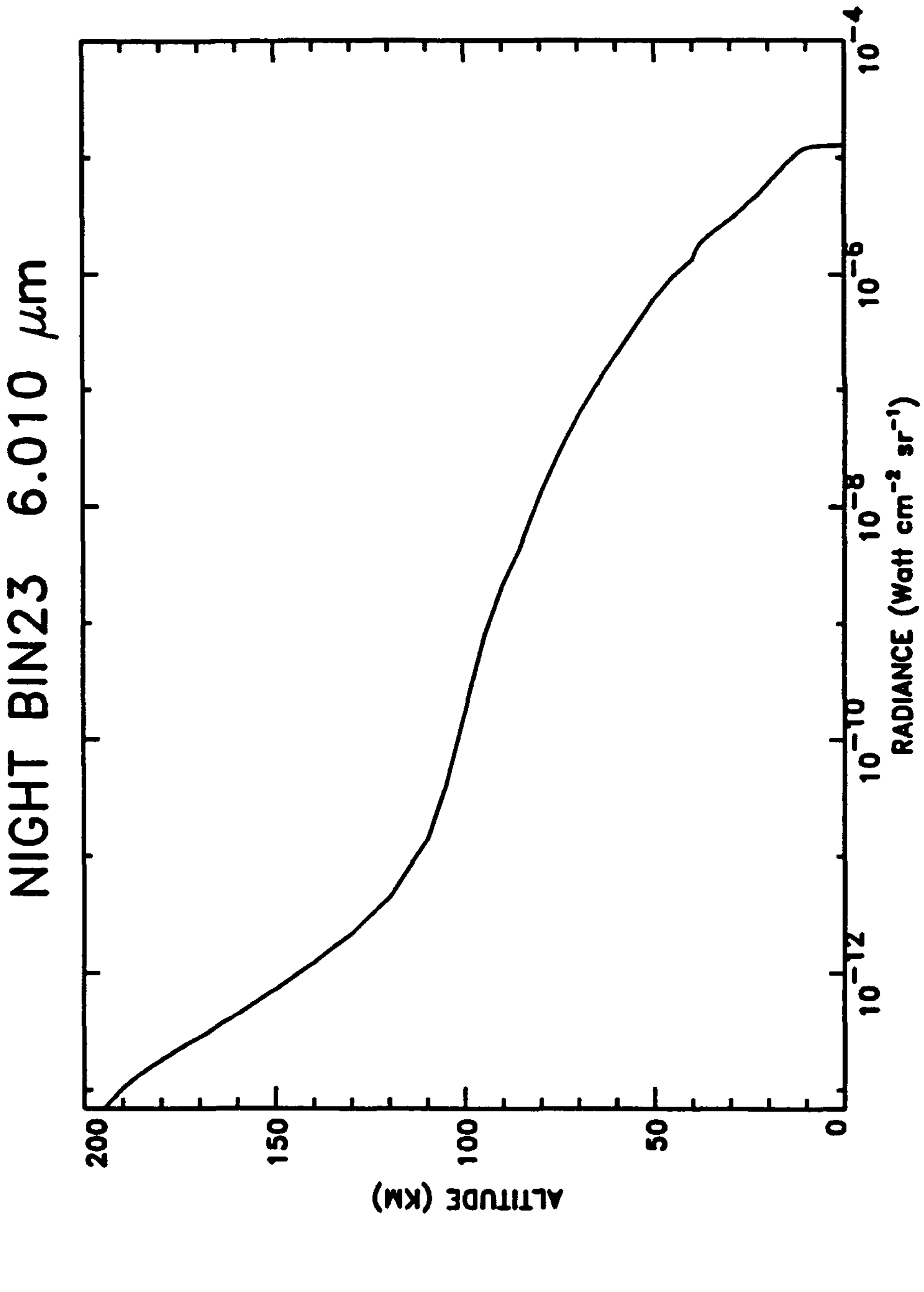

NIGHT BIN20 5.172 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-12}
10^{-10}
10^{-8}
10^{-6}

NIGHT BIN21 5.438 μm

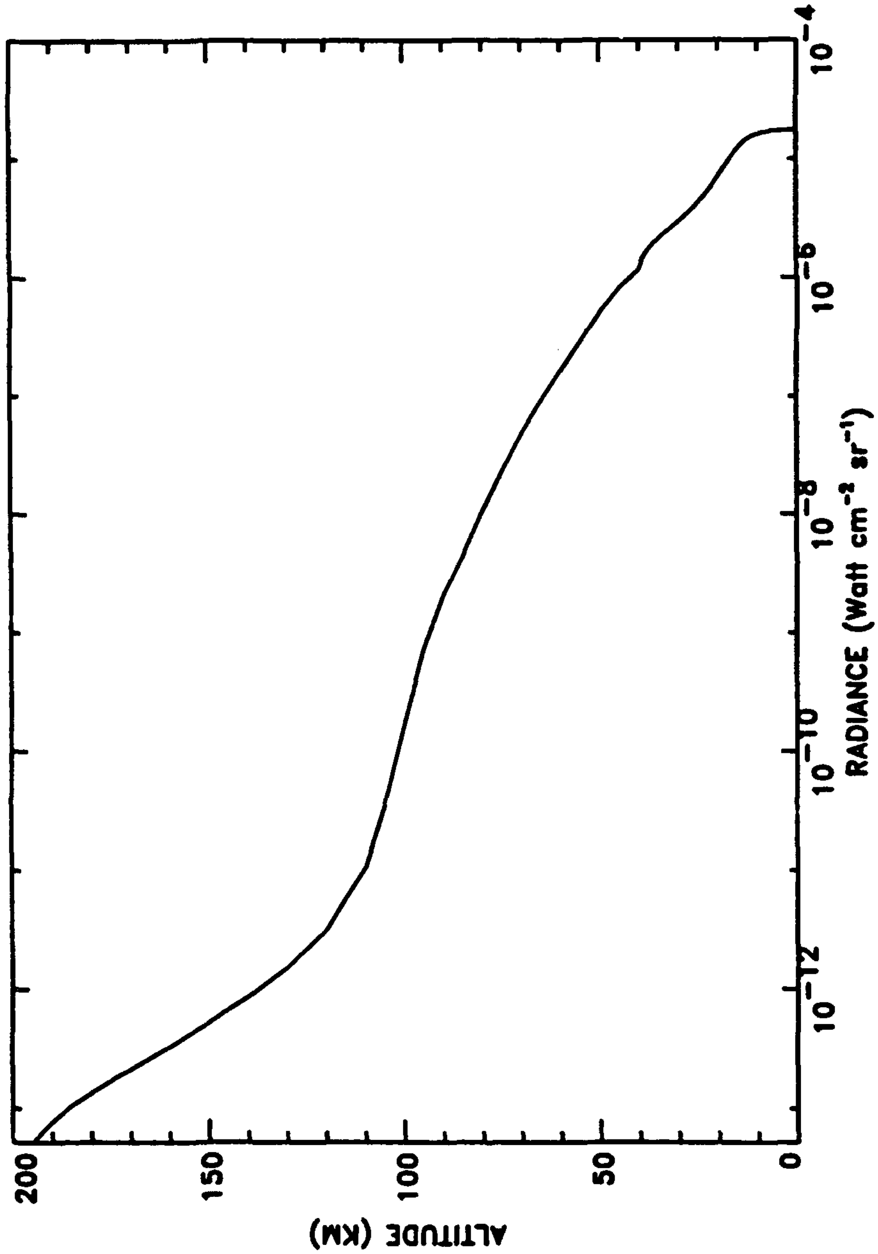


NIGHT BIN22 5.717 μm

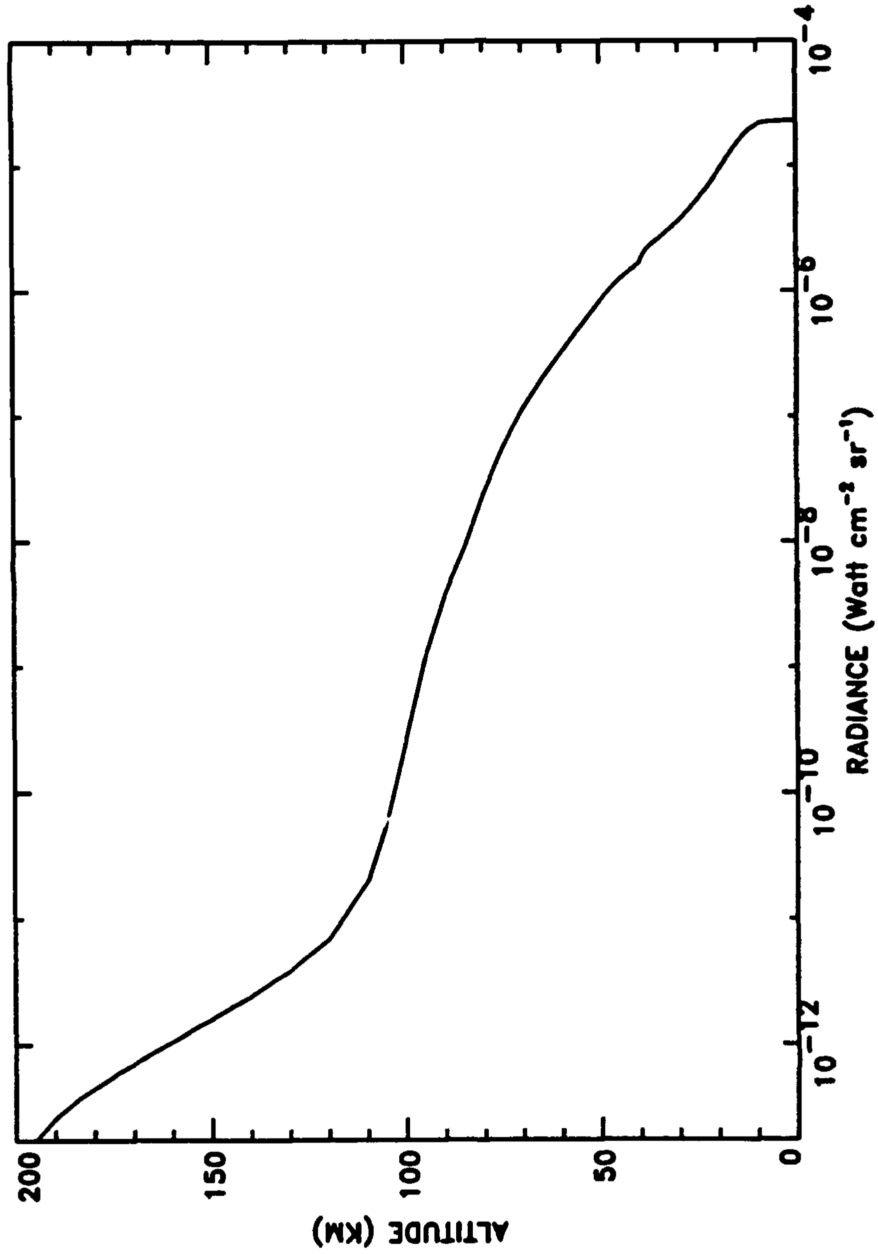


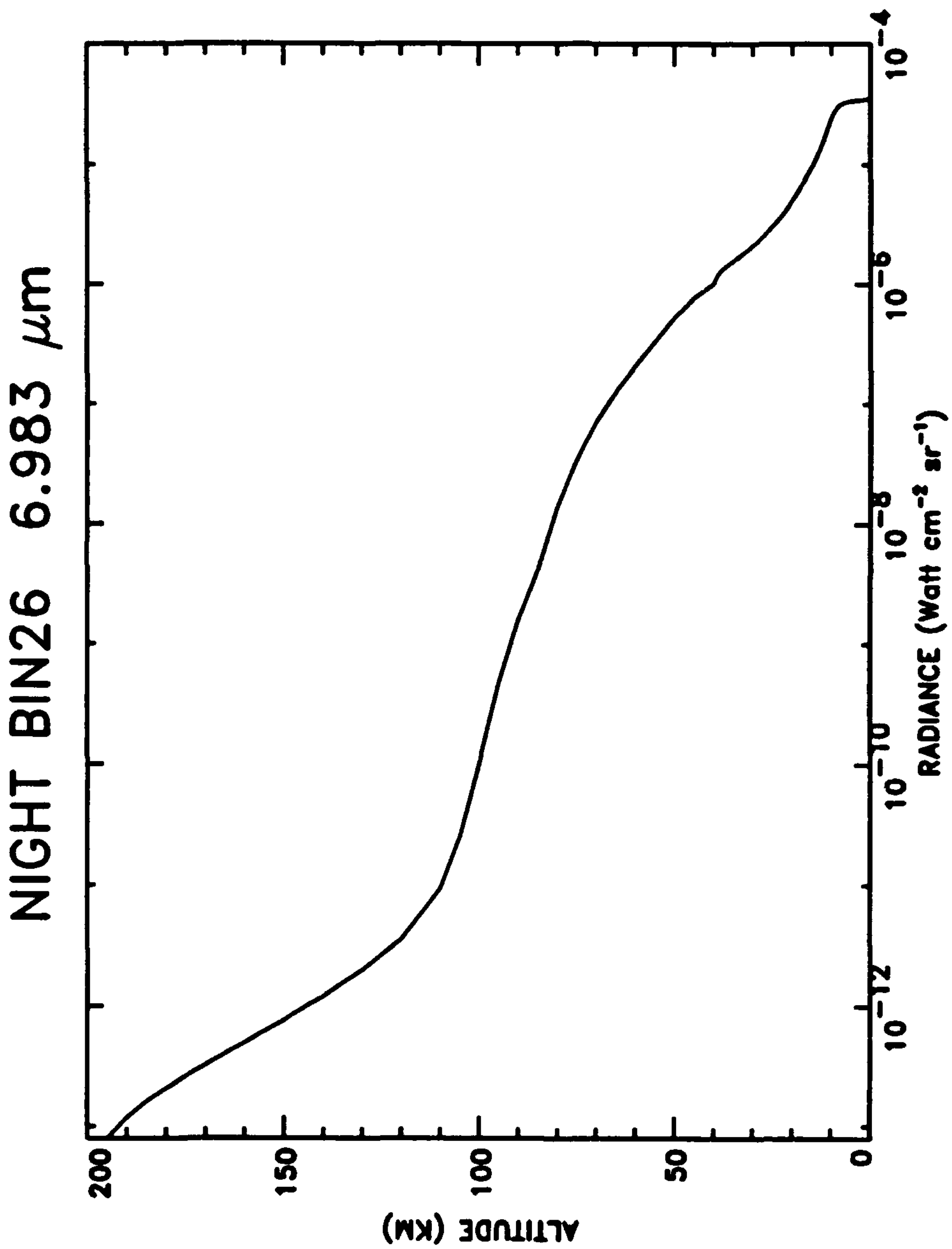

NIGHT BIN23 6.010 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm-2 sr-1)
10-12
10-10
10-8
10-6
10-4

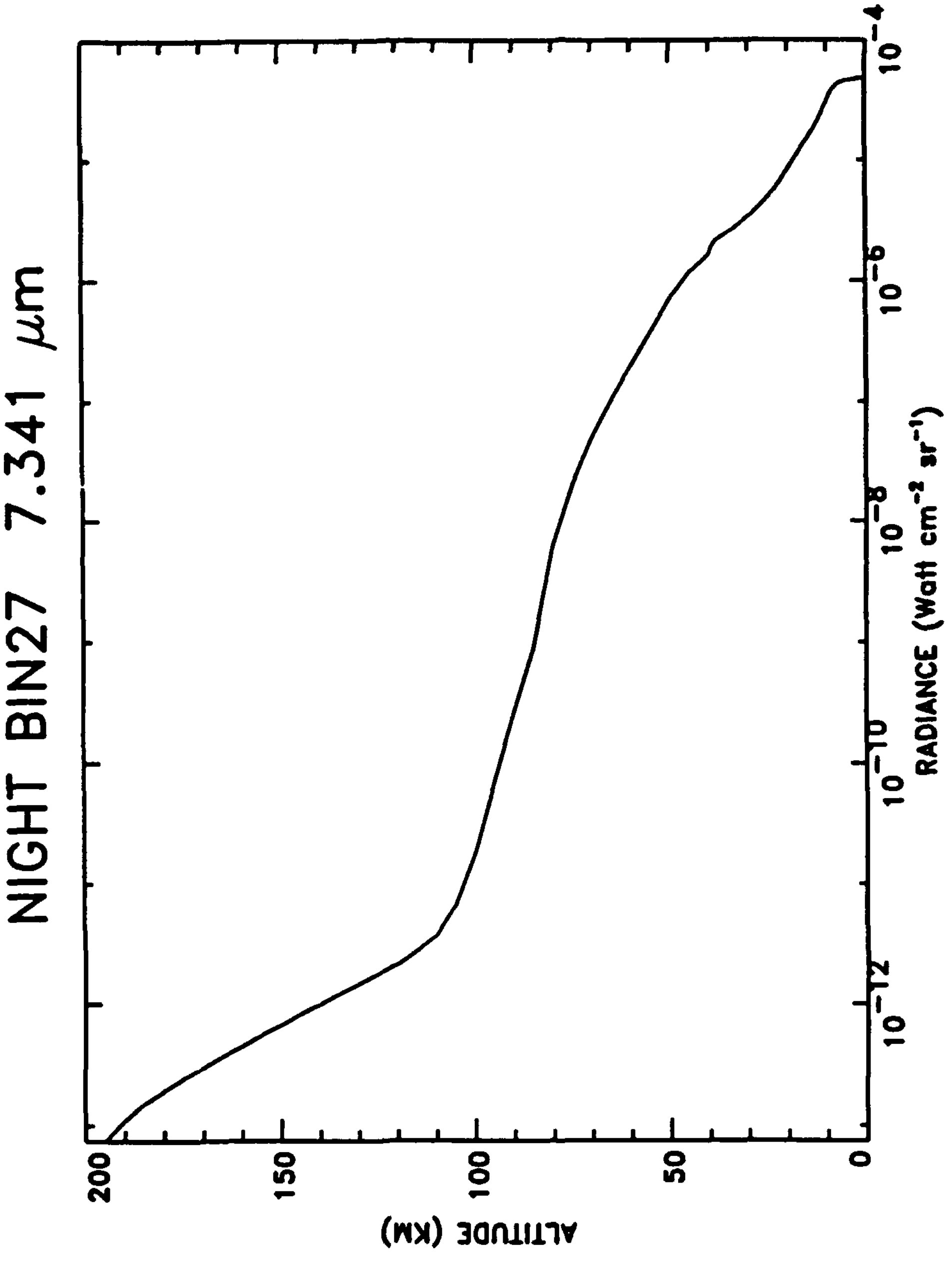
NIGHT BIN24 6.318 μm

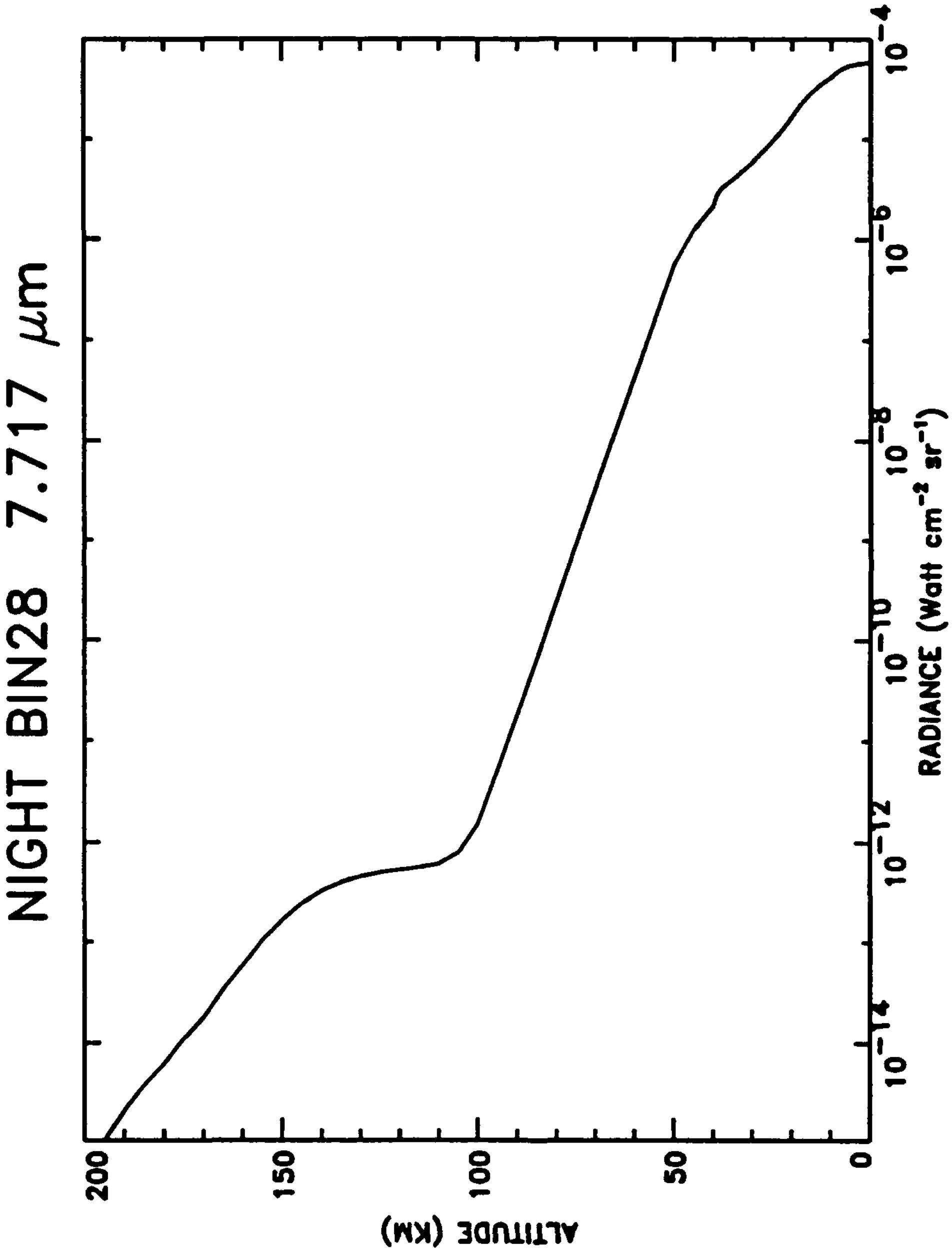


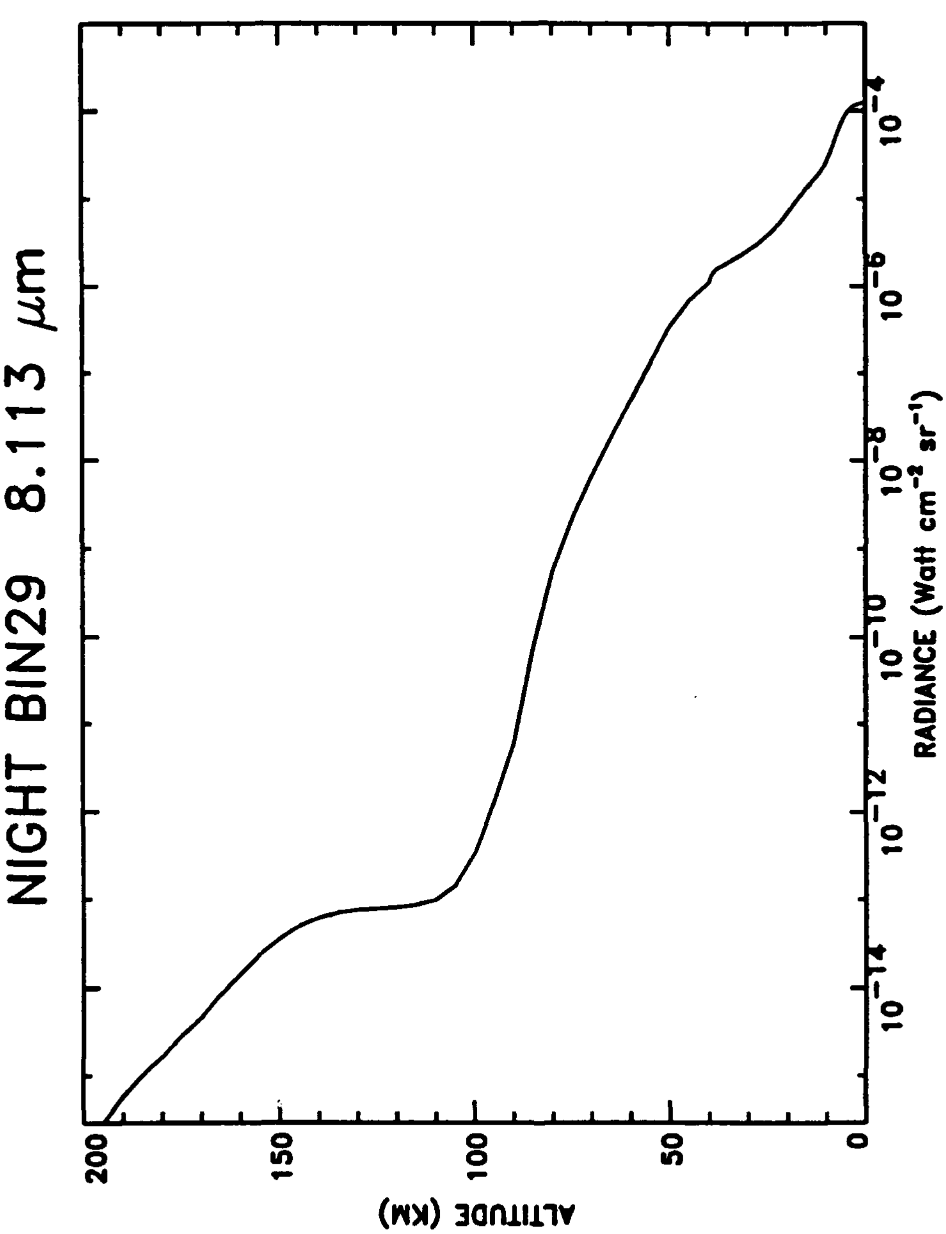
NIGHT BIN25 6.642 μm



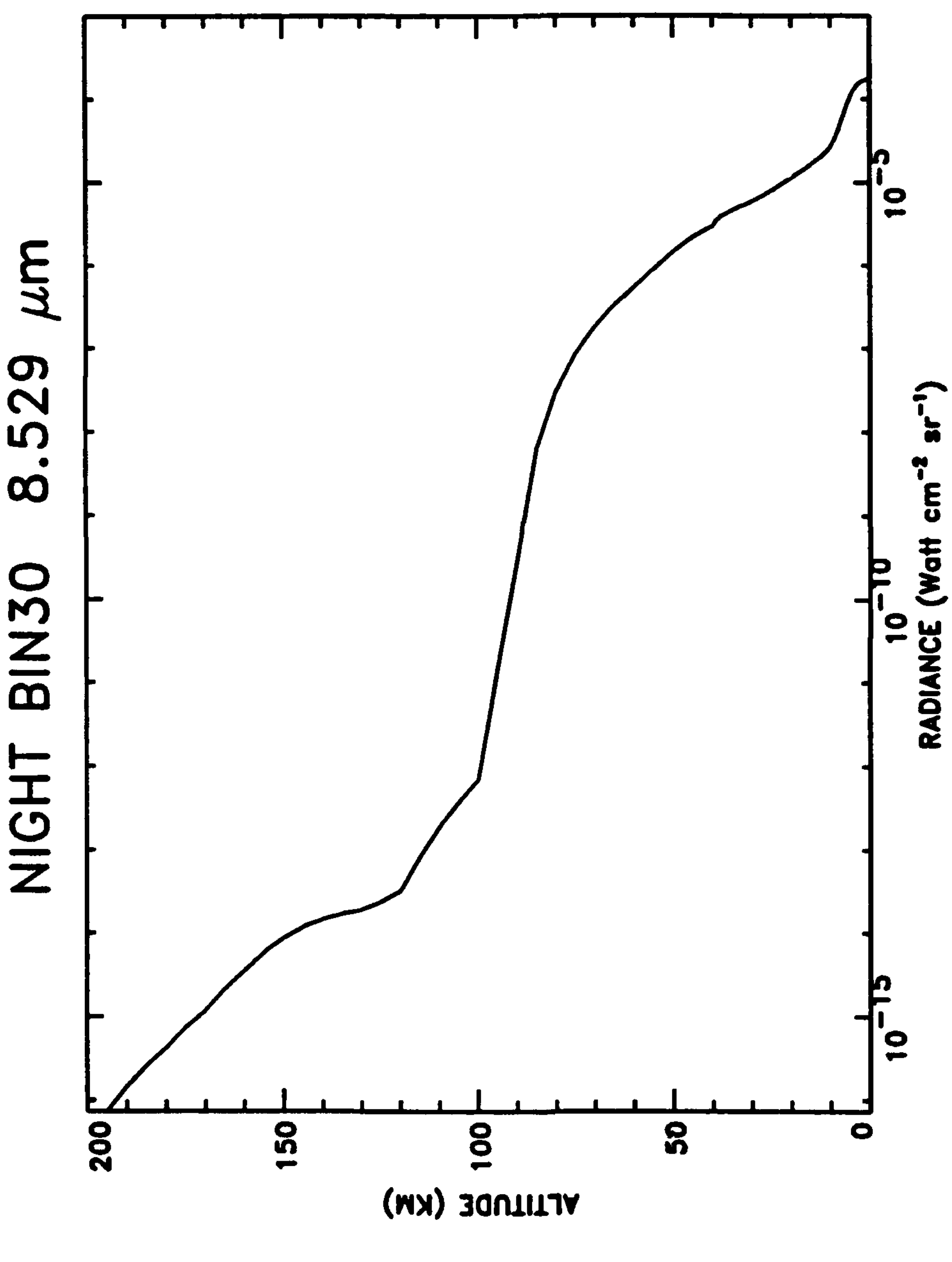

NIGHT BIN26 6.983 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

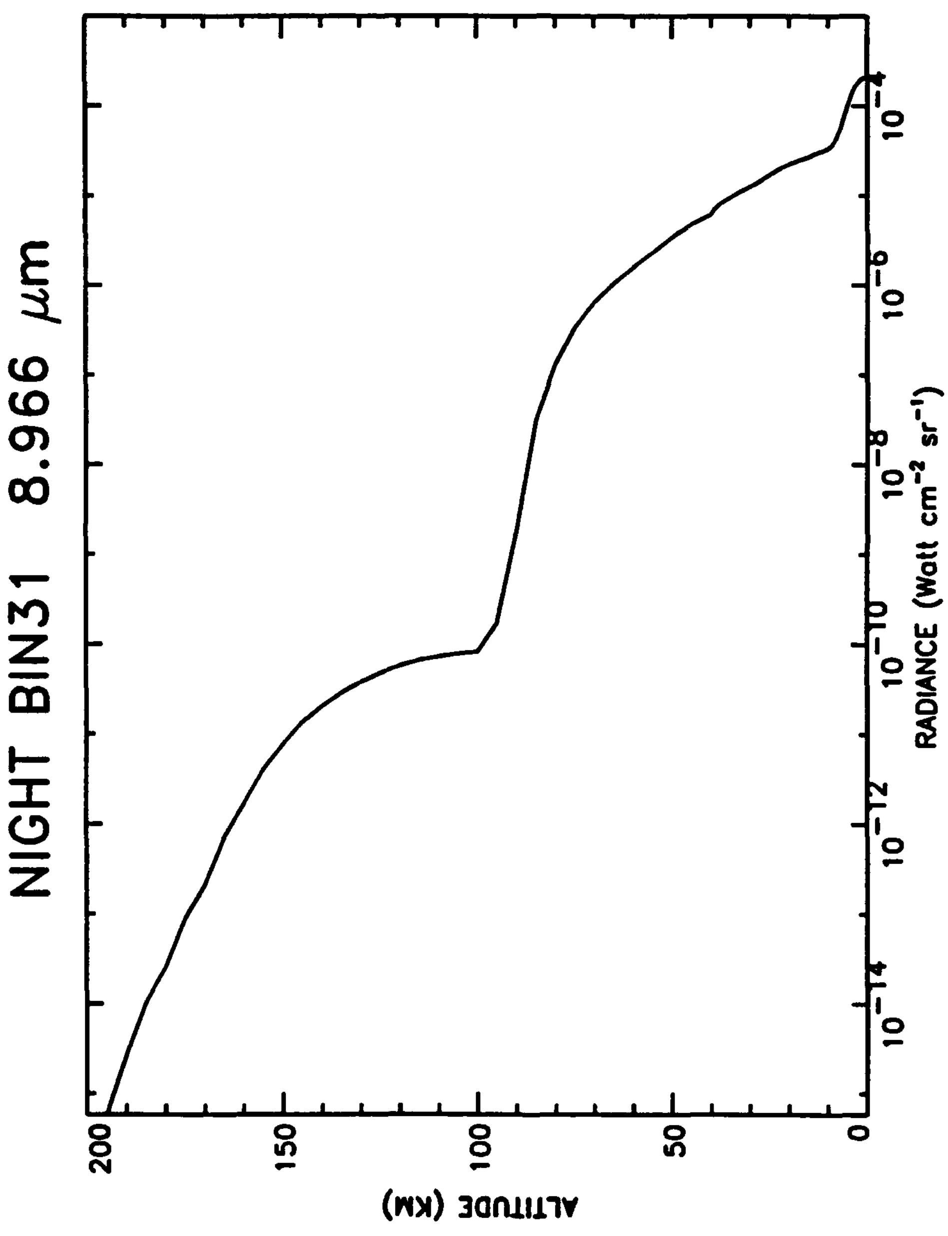

NIGHT BIN27 7.341 μm
ALTITUDE (KM)
200
150
100
50
0
10^-12
10^-10
10^-8
10^-6
10^-4
RADIANCE (Watt cm^-2 sr^-1)


NIGHT BIN28 7.717 μm
ALTITUDE (KM)
200
150
100
50
0
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
RADIANCE (Watt cm^{-2} sr^{-1})

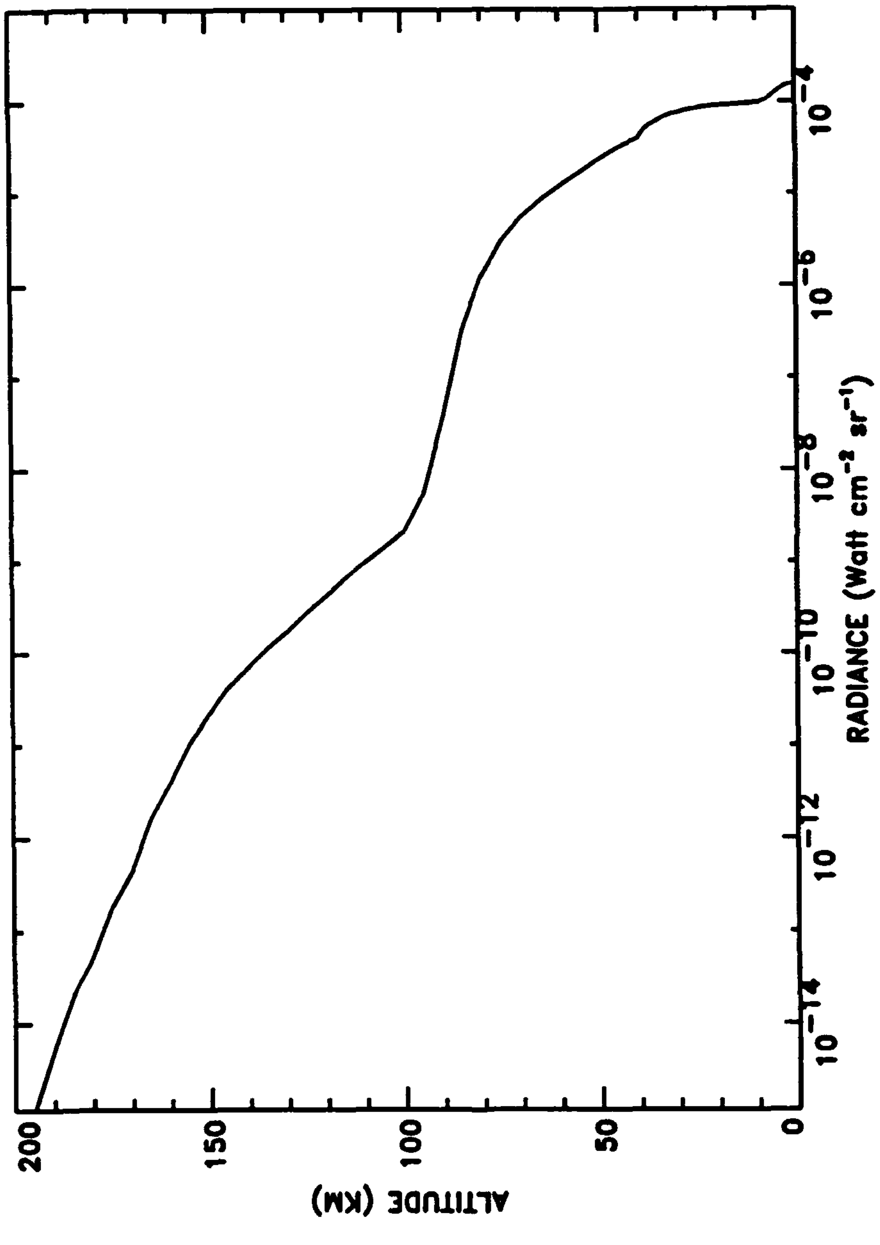


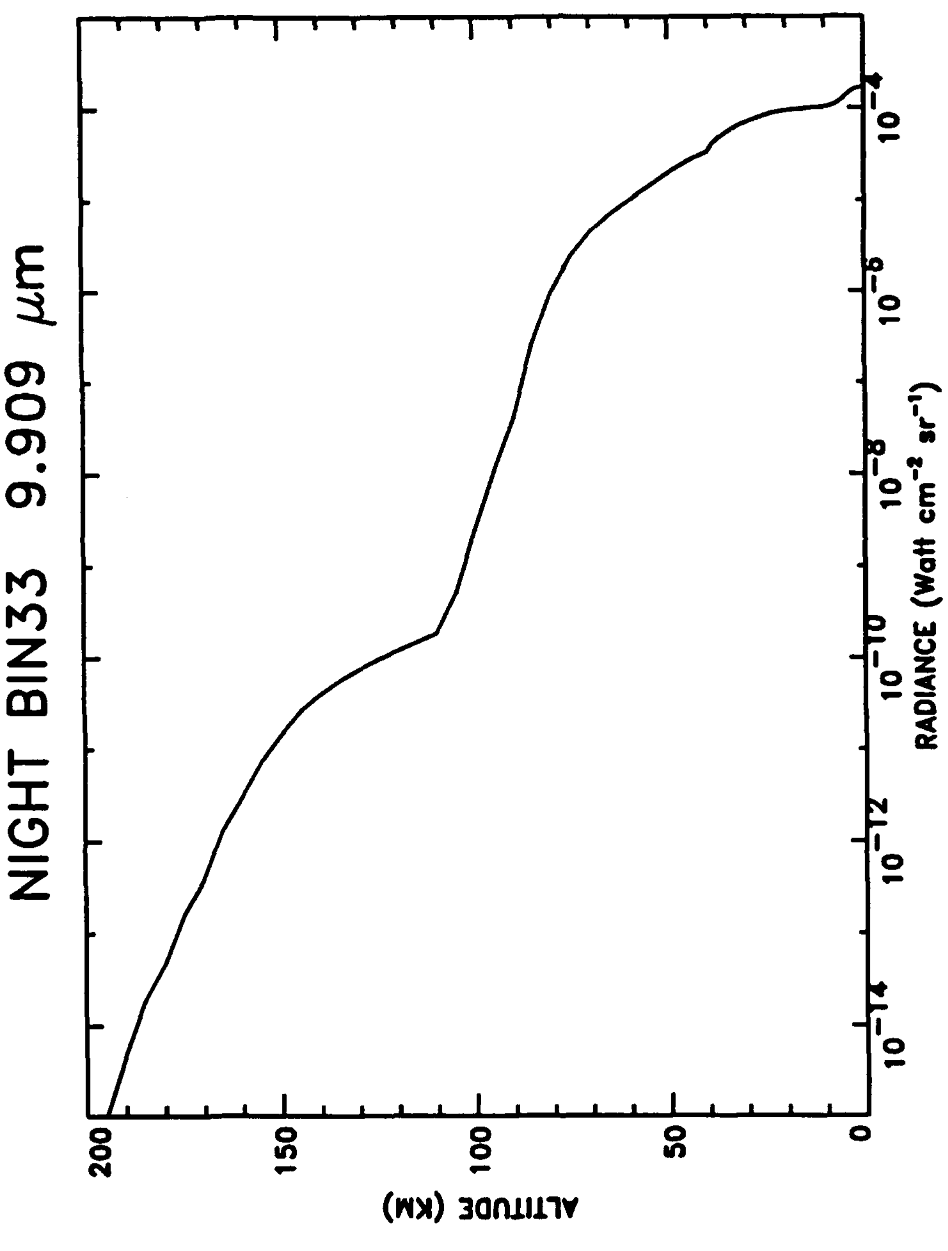
NIGHT BIN29 8.113 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}


NIGHT BIN30 8.529 μm
ALTITUDE (KM)
RADIANCE (Watt cm⁻² sr⁻¹)
200
150
100
50
0
10⁻¹⁵
10⁻¹⁰
10⁻⁵

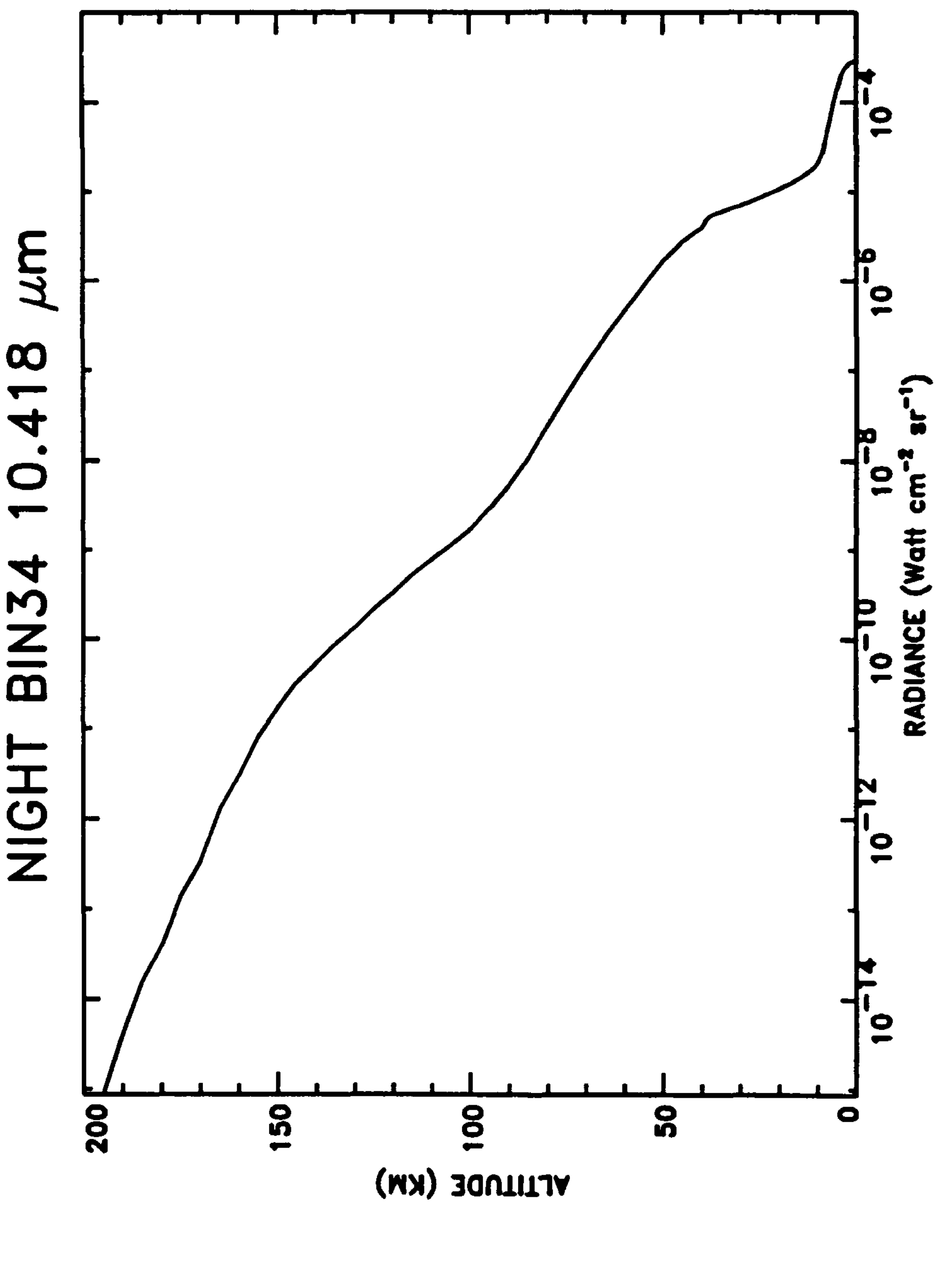

NIGHT BIN31 8.966 μm
ALTITUDE (KM)
RADIANCE (Watt cm^{-2} sr^{-1})
0
50
100
150
200
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}

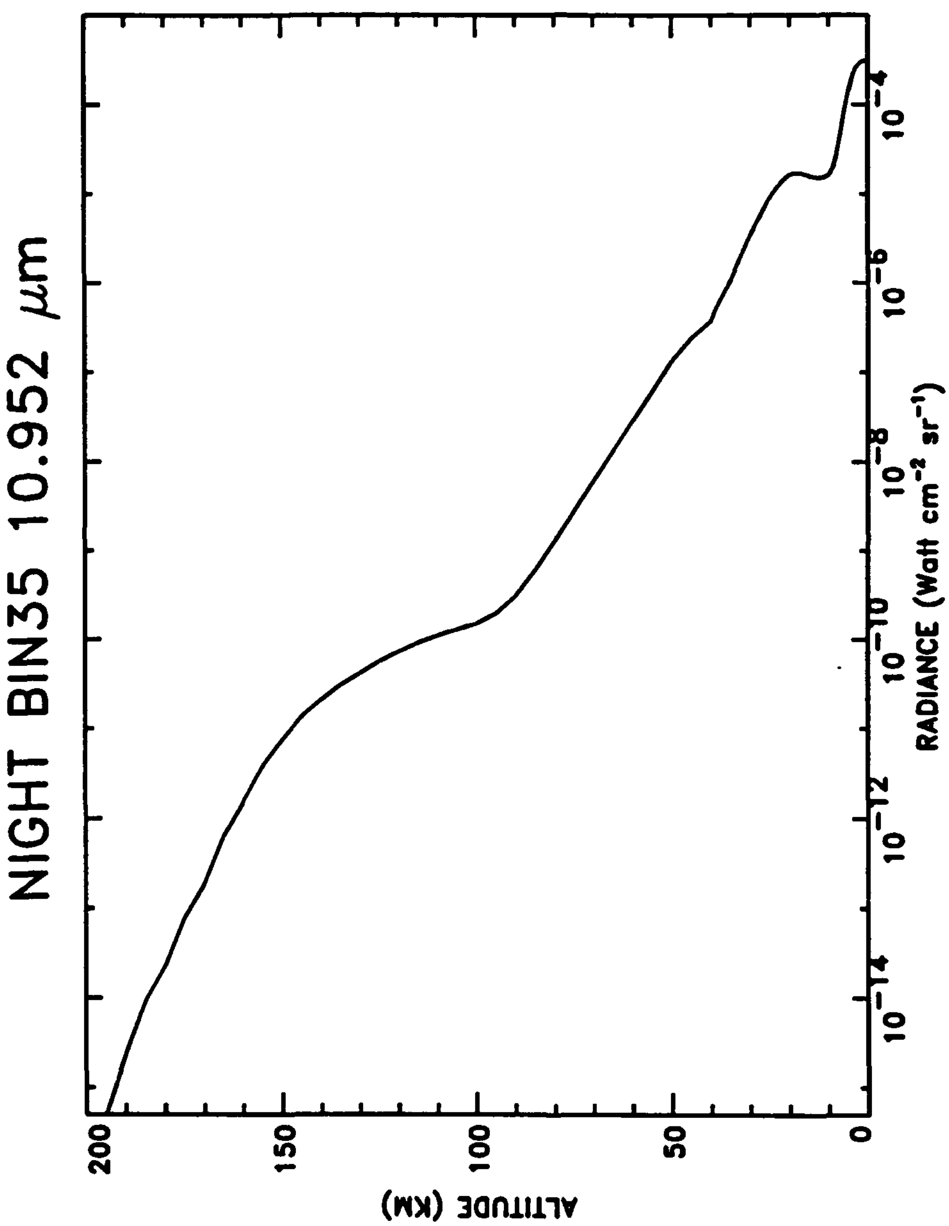
NIGHT BIN32 9.426 μm





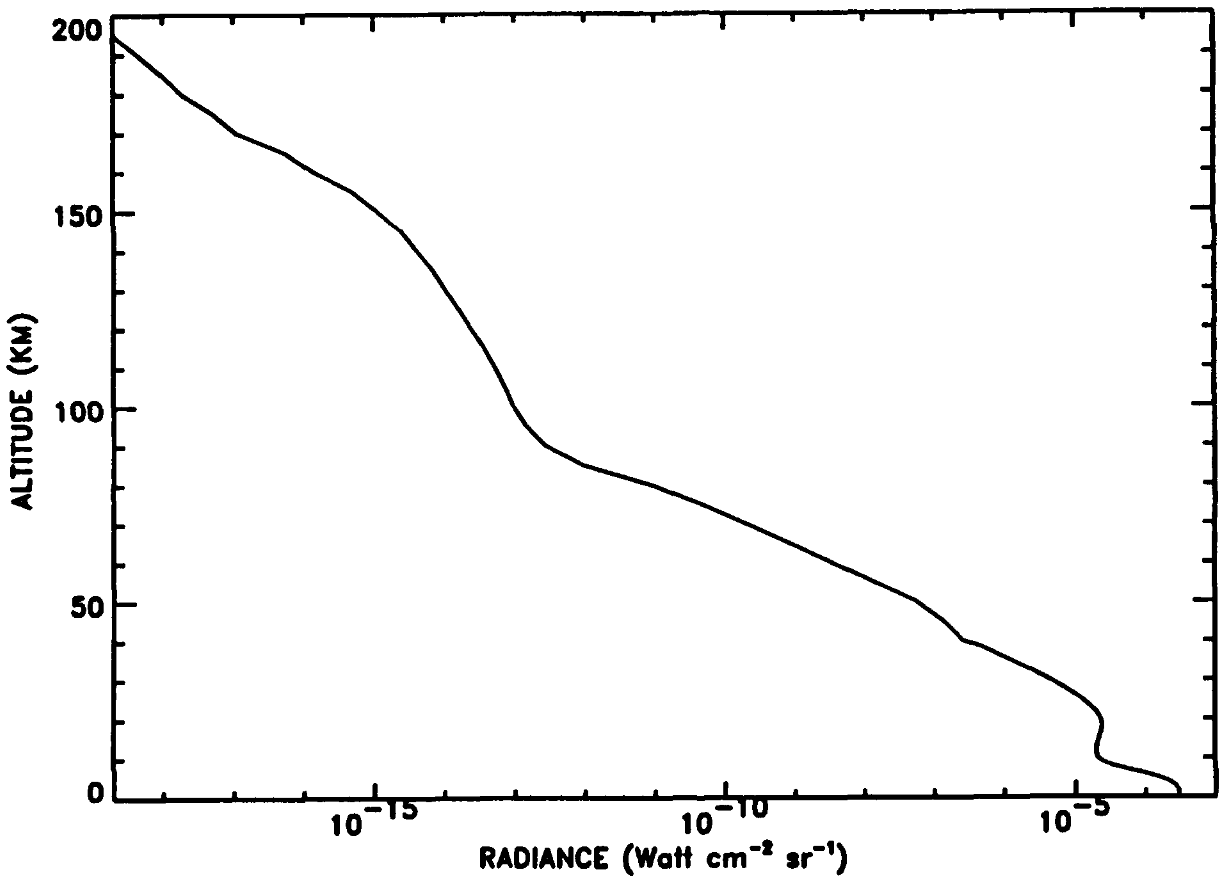
NIGHT BIN33 9.909 μm
ALTITUDE (KM)
RADIANCE (Watt cm⁻² sr⁻¹)
200
150
100
50
0
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

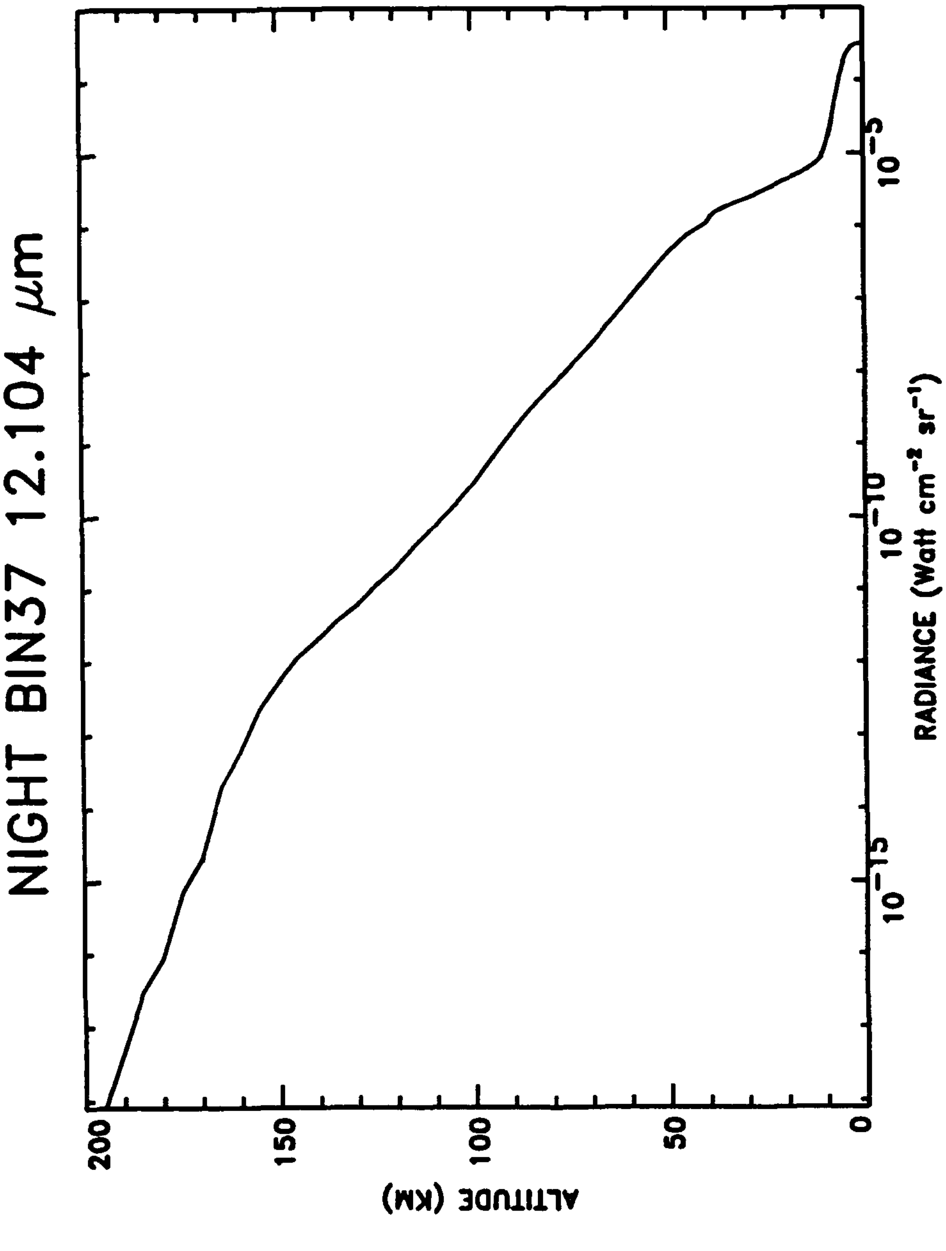

NIGHT BIN34 10.418 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴



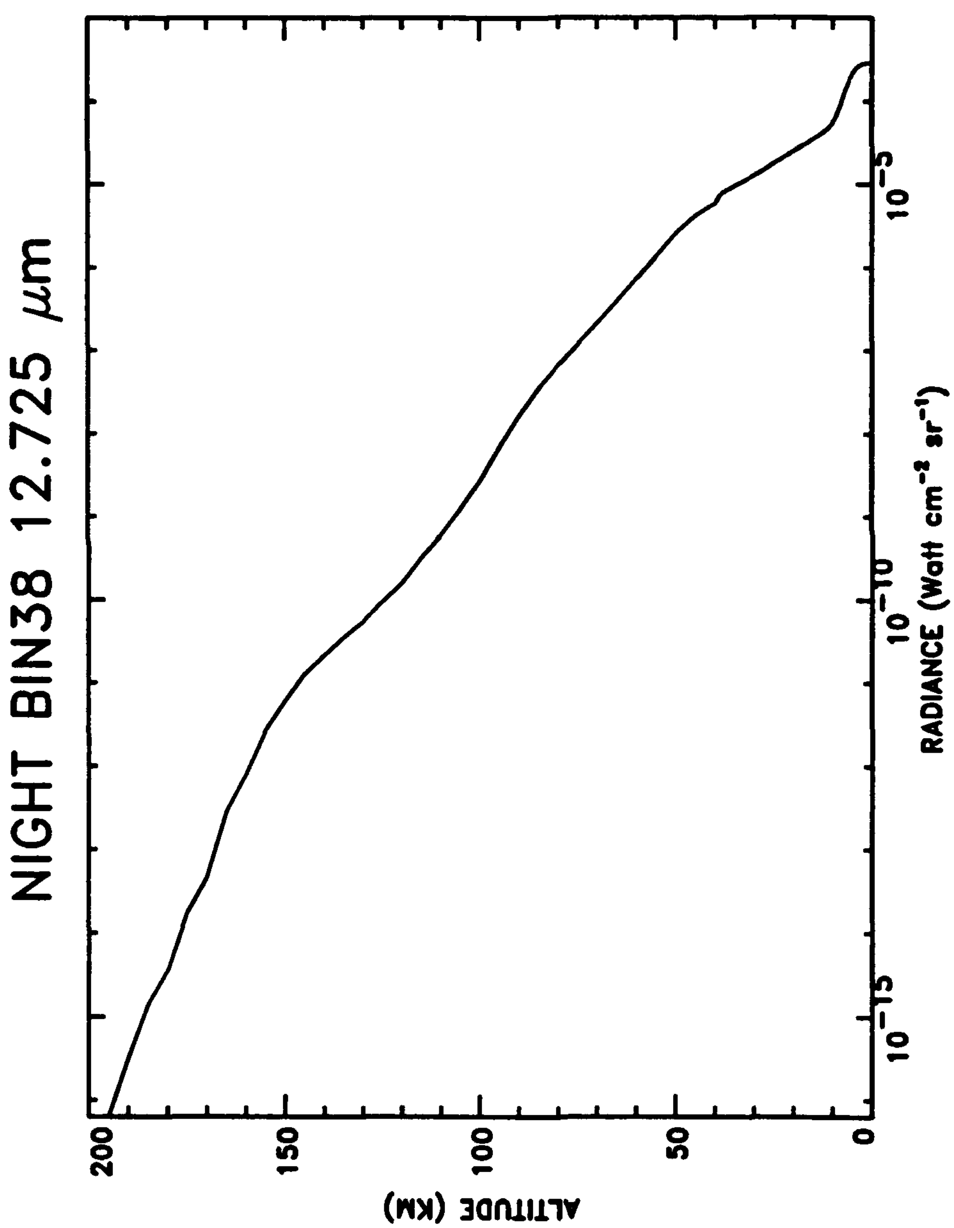
NIGHT BIN35 10.952 μm
ALTITUDE (KM)
RADIANCE (Watt cm^{-2} sr^{-1})
200
150
100
50
0
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}

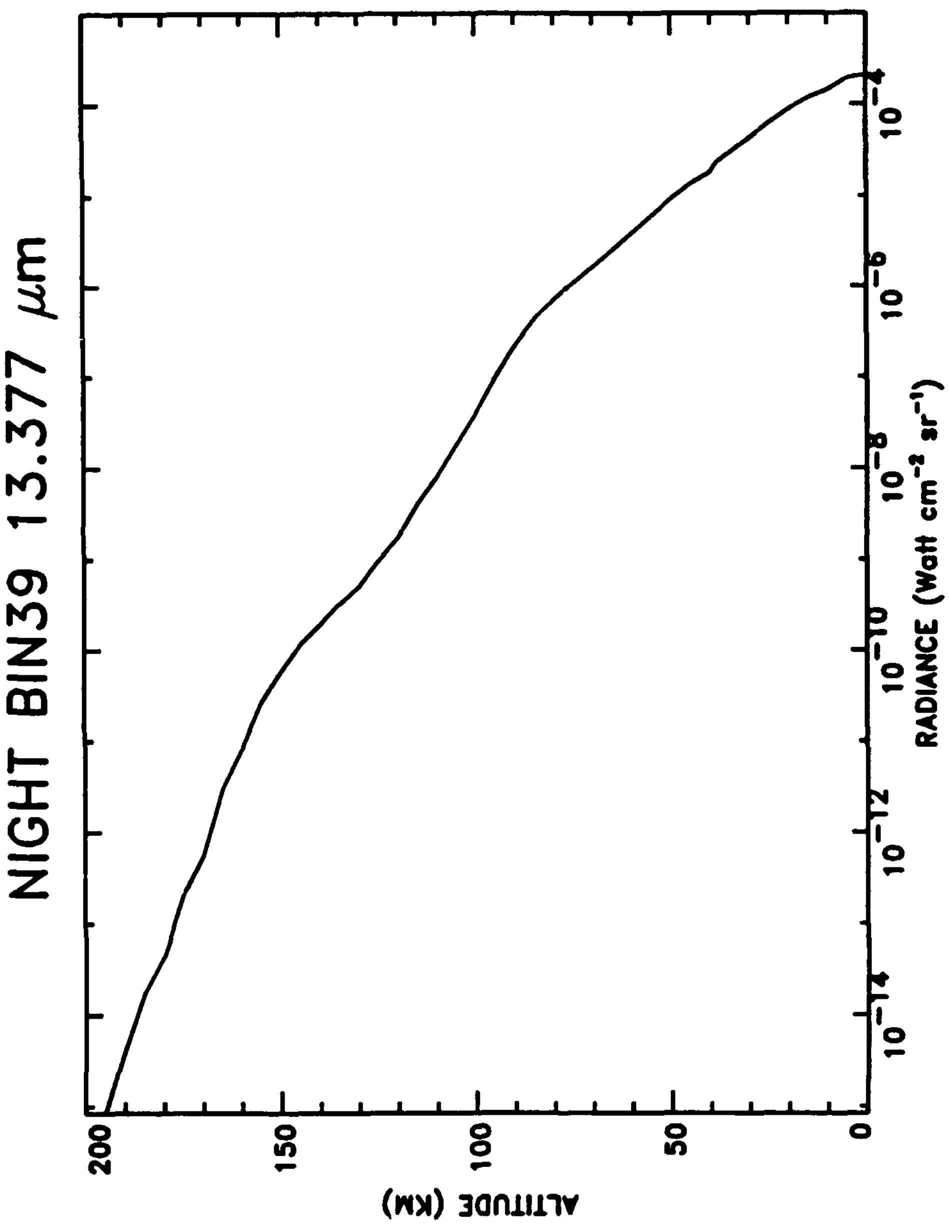
NIGHT BIN36 11.513 μm



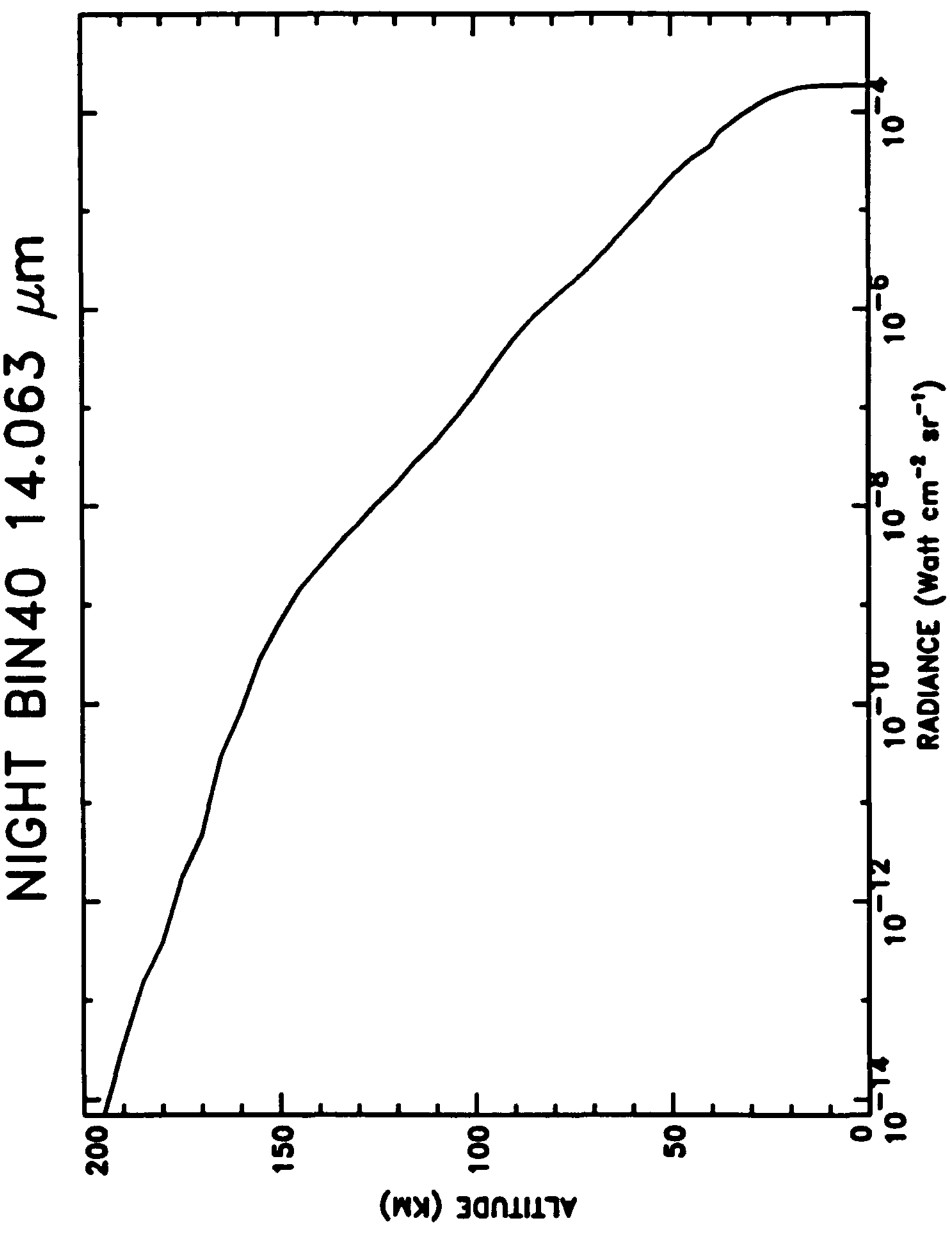


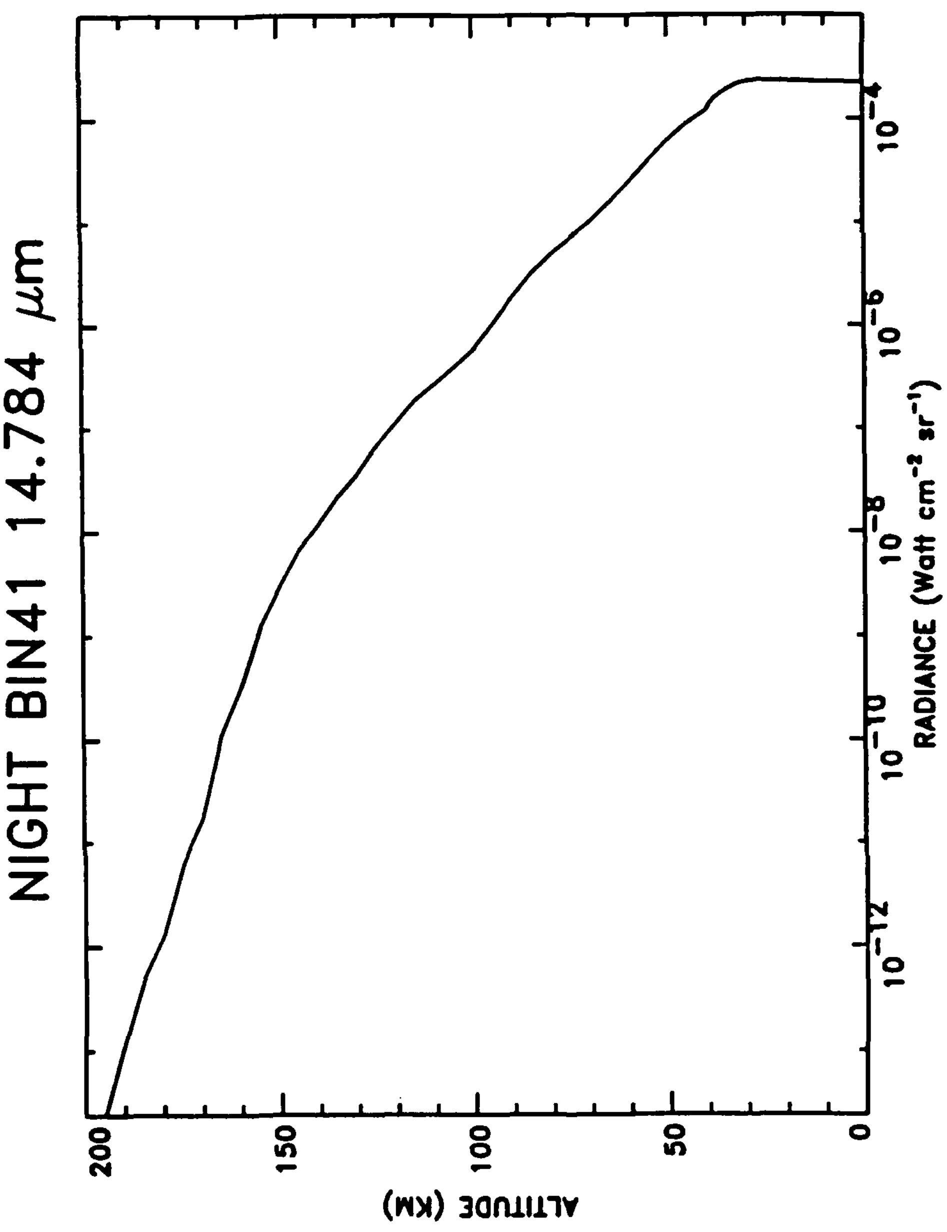
NIGHT BIN37 12.104 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁵
10⁻¹⁰
10⁻⁵


NIGHT BIN38 12.725 μm
ALTITUDE (KM)
200
150
100
50
0
10^{-15}
10^{-10}
10^{-5}
RADIANCE (Watt cm^{-2} sr^{-1})

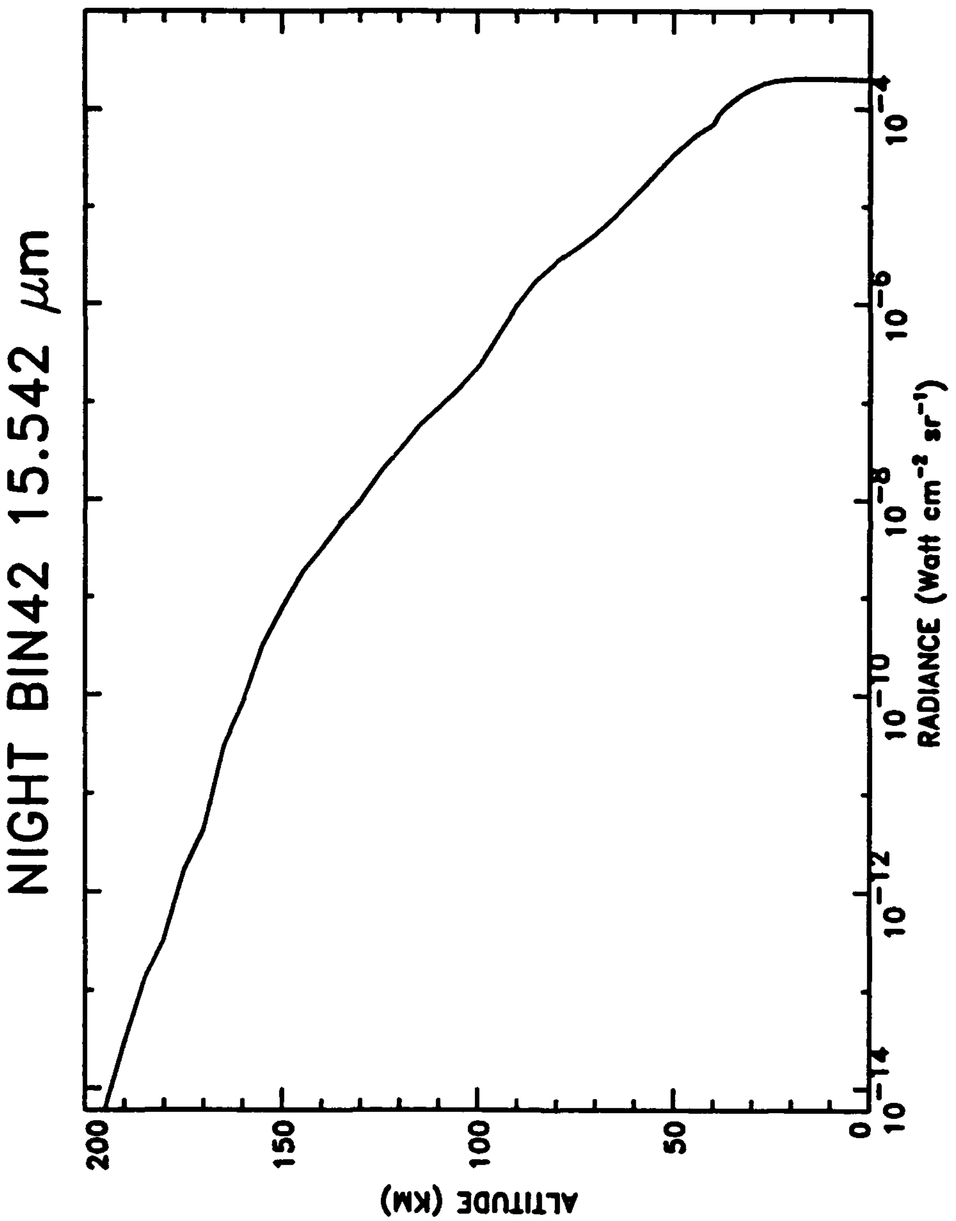


NIGHT BIN39 13.377 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁴
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

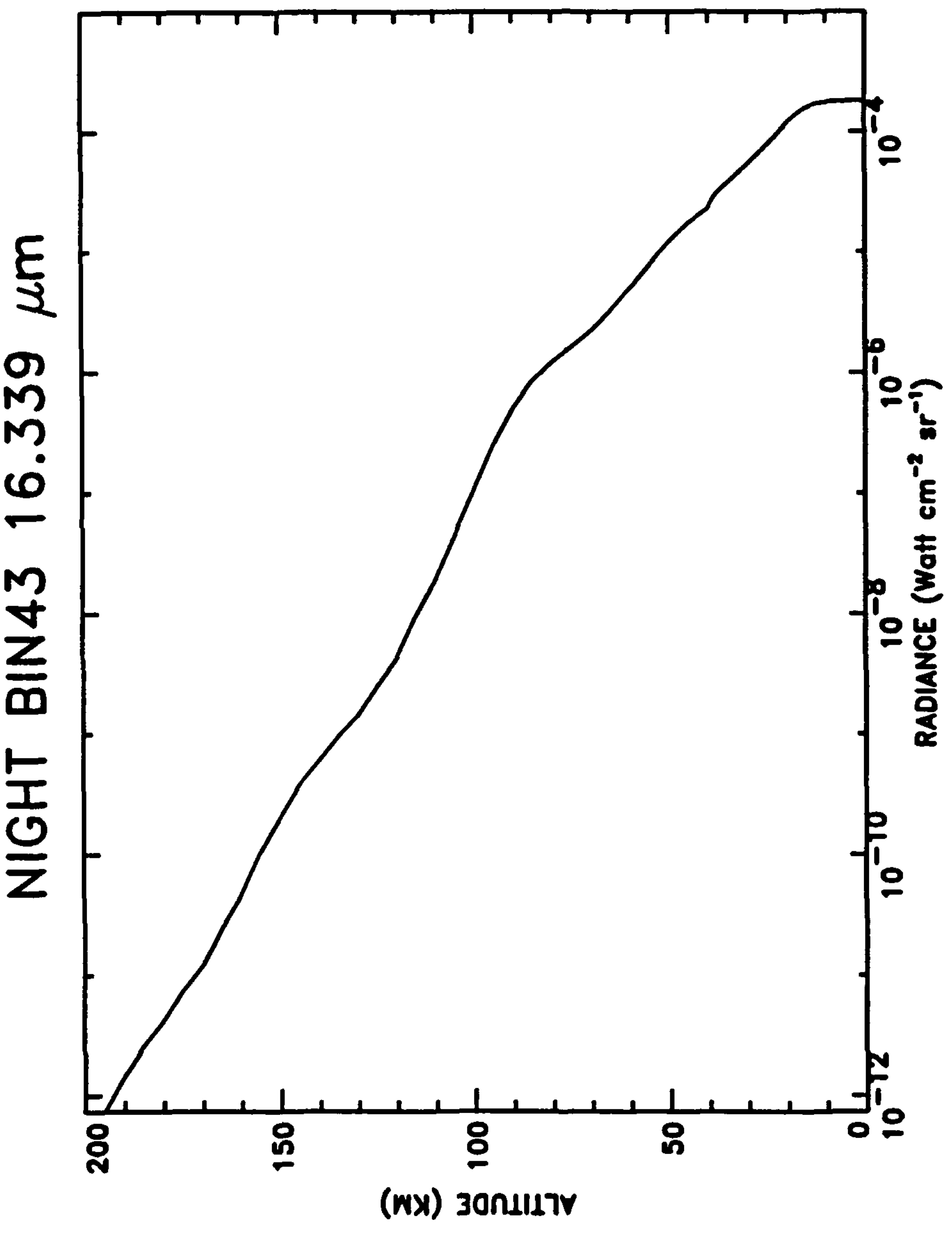

NIGHT BIN40 14.063 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^-2 sr^-1)
10^-14
10^-12
10^-10
10^-8
10^-6
10^-4



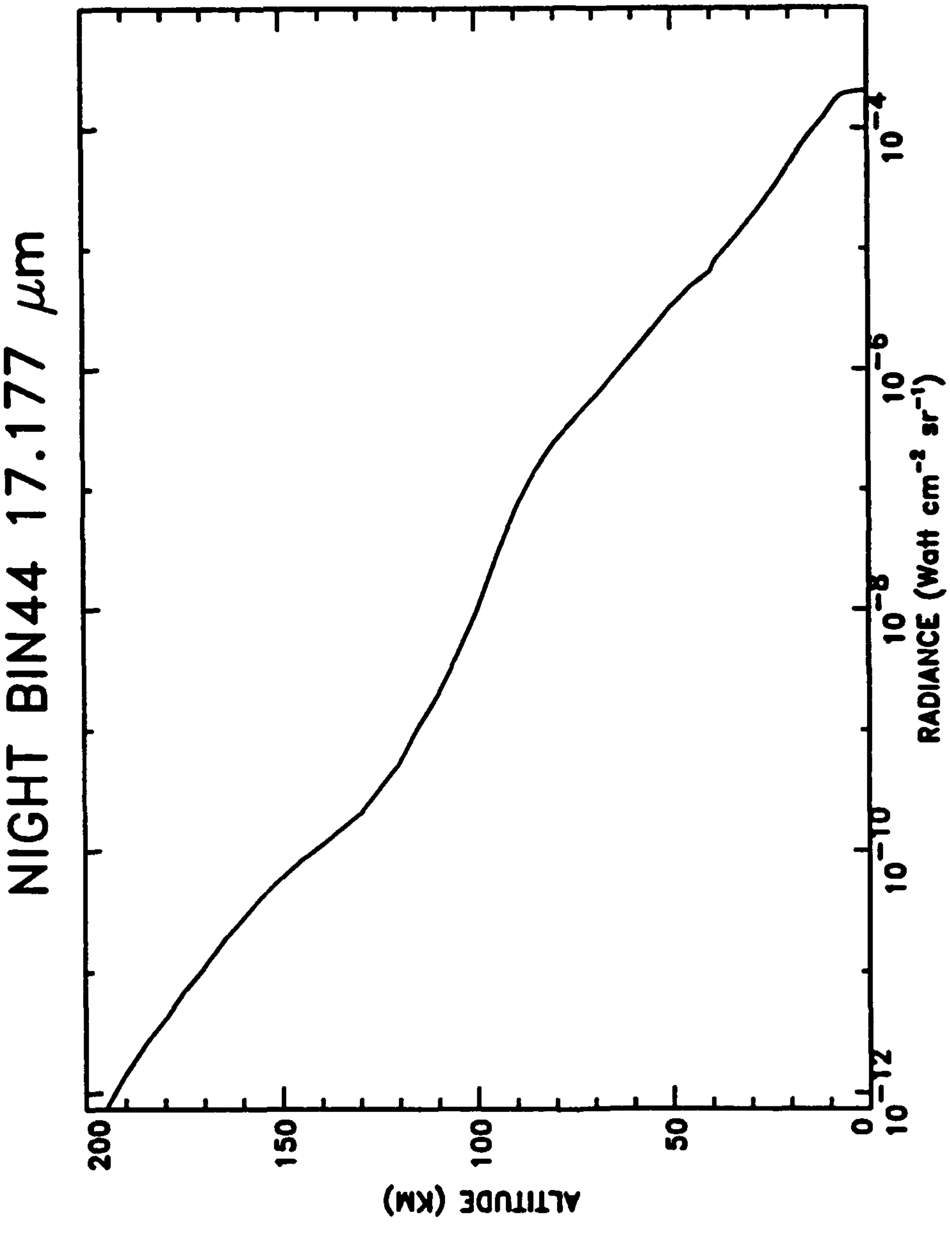
NIGHT BIN41 14.784 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

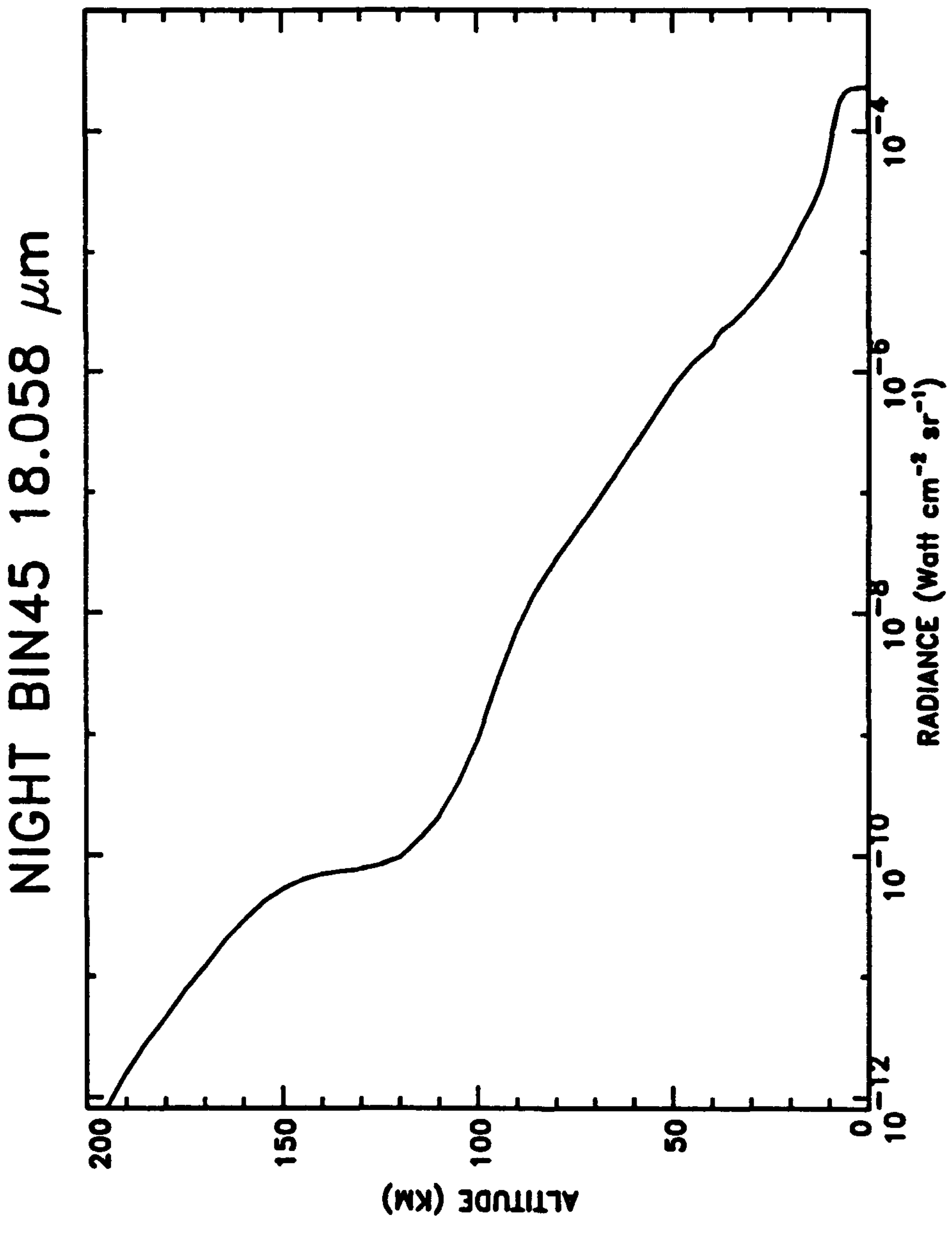


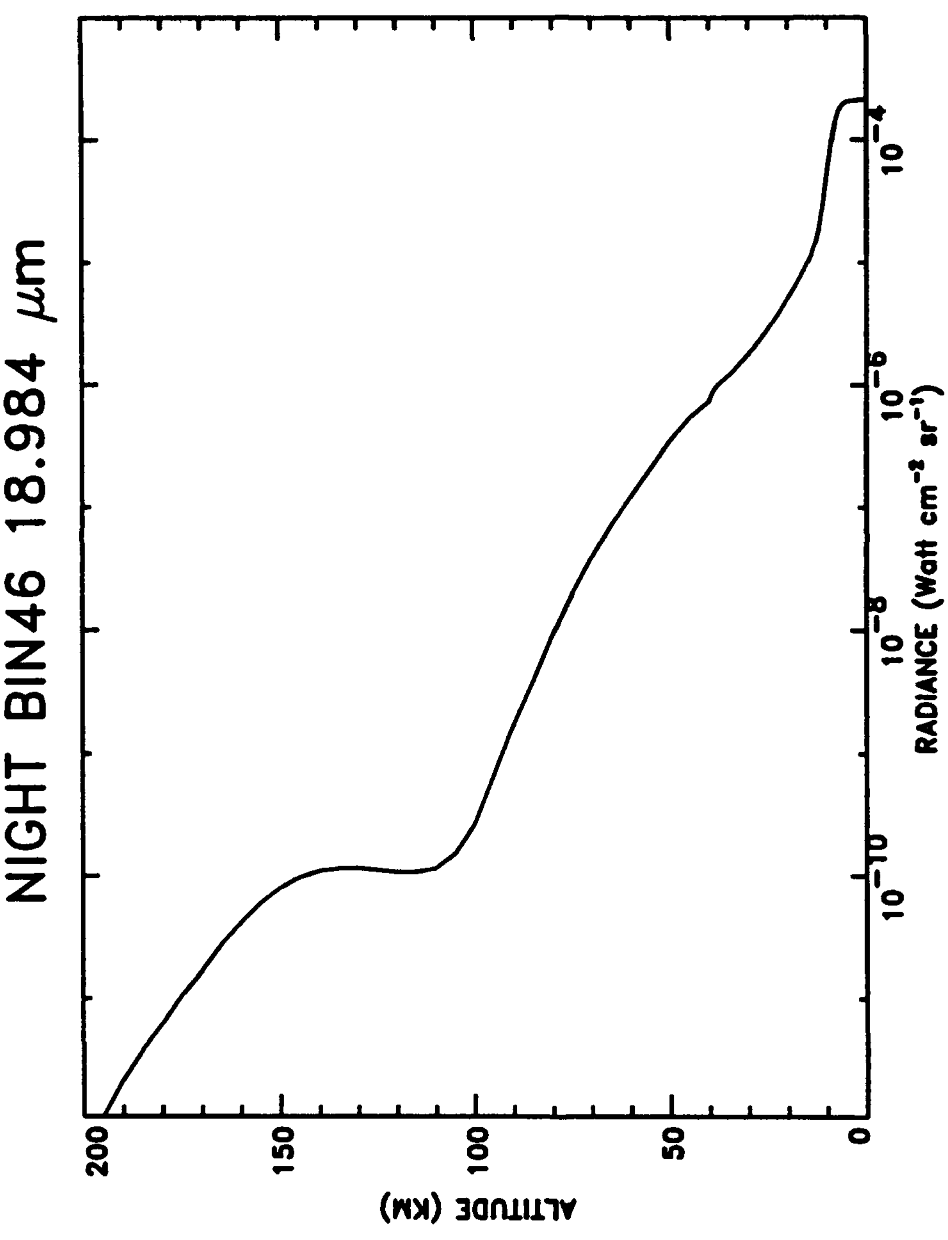
NIGHT BIN42 15.542 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^-2 sr^-1)
10^-14
10^-12
10^-10
10^-8
10^-6
10^-4



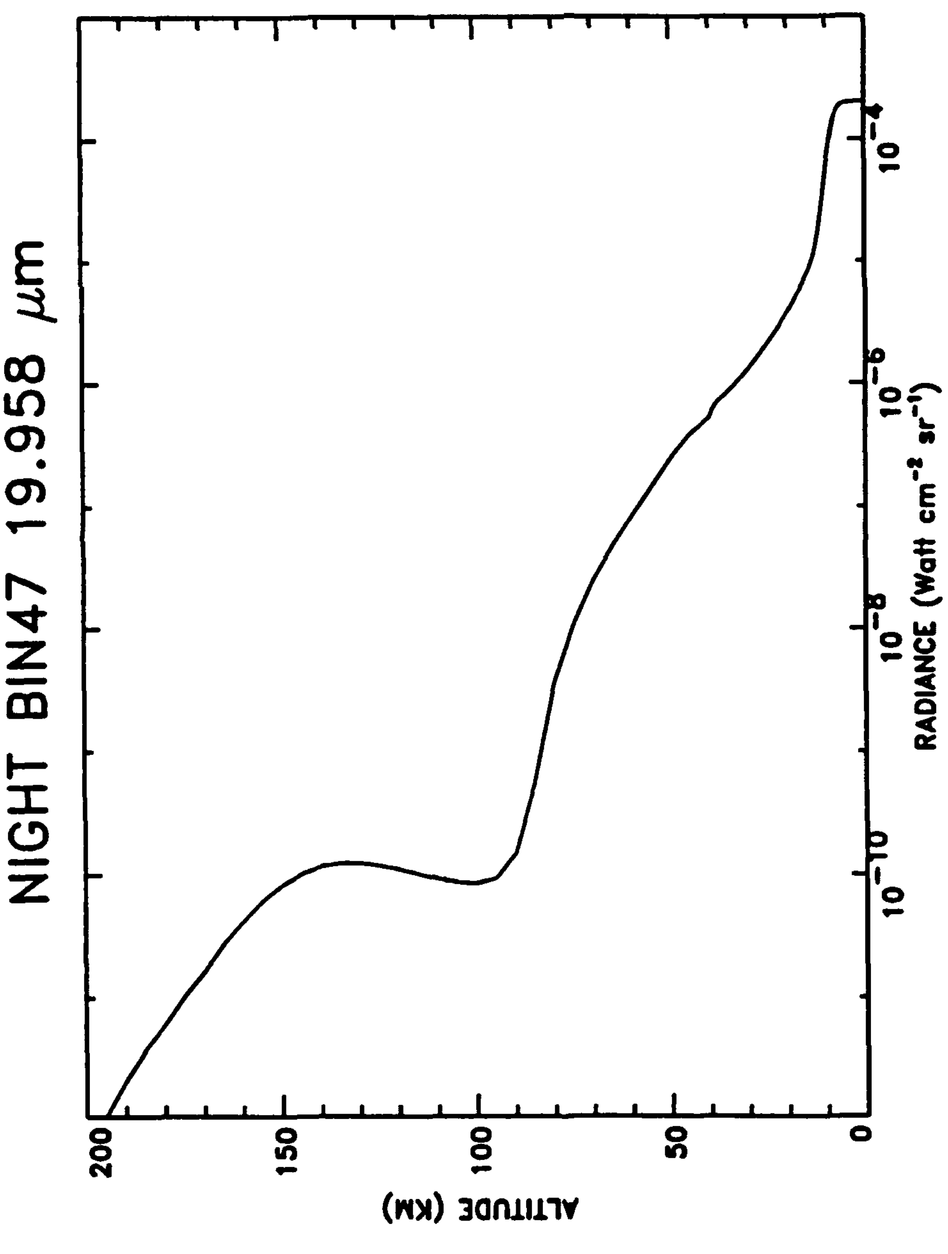
NIGHT BIN43 16.339 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm^{-2} sr^{-1})
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}

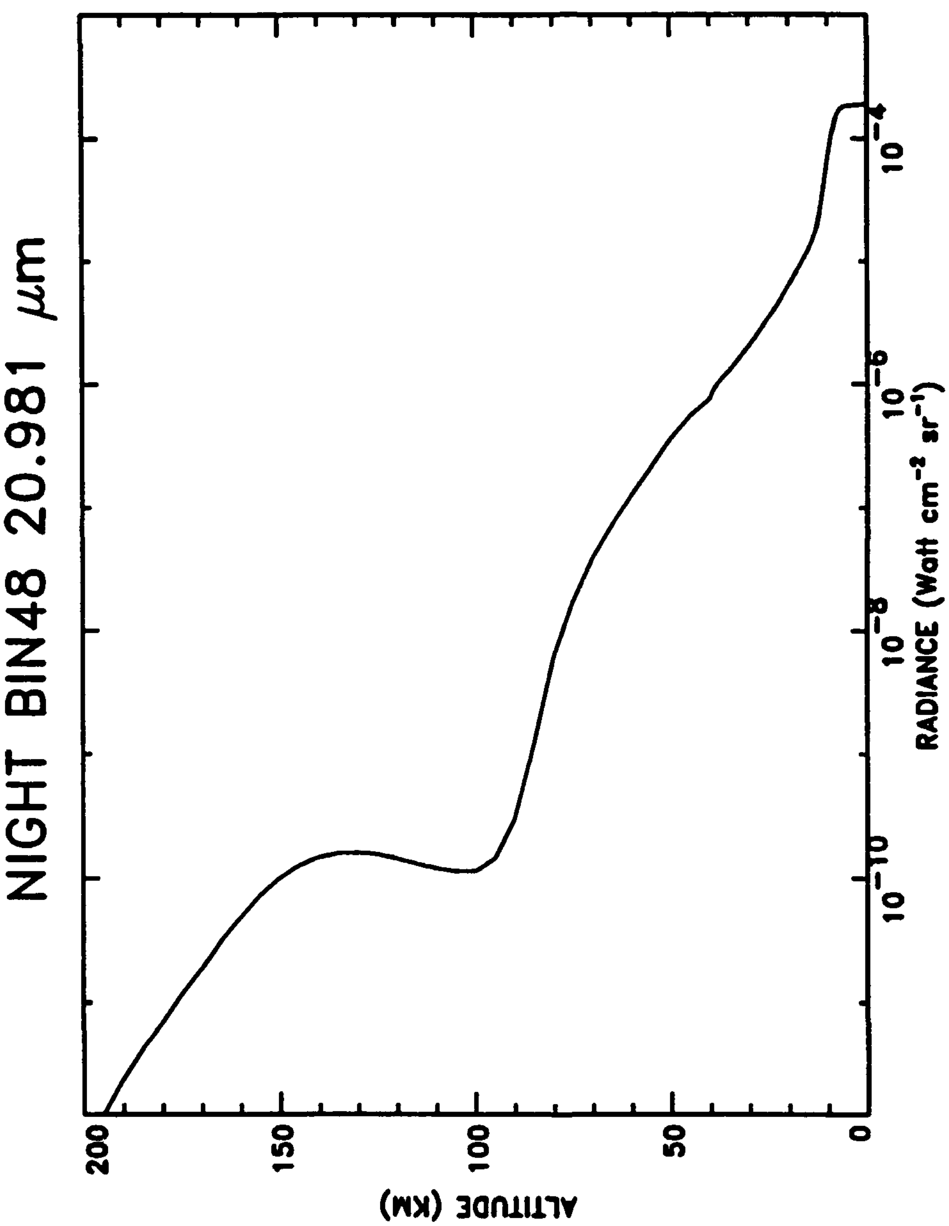

NIGHT BIN44 17.177 μm
ALTITUDE (KM)
0
50
100
150
200
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴


NIGHT BIN45 18.058 μm
ALTITUDE (KM)
0
50
100
150
200
RADIANCE (Watt cm^-2 sr^-1)
10^-12
10^-10
10^-8
10^-6
10^-4



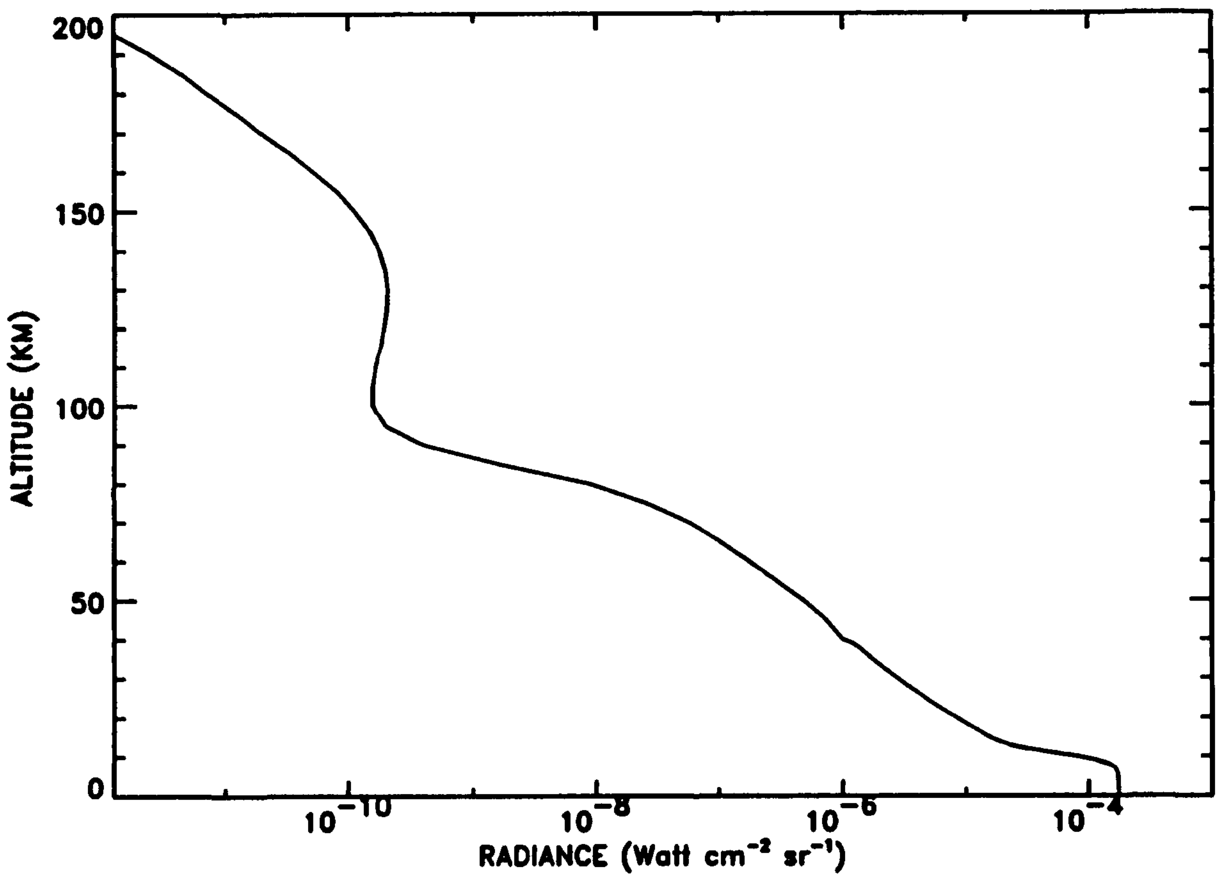
NIGHT BIN46 18.984 μm
ALTITUDE (KM)
RADIANCE (Watt cm⁻² sr⁻¹)
200
150
100
50
0
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

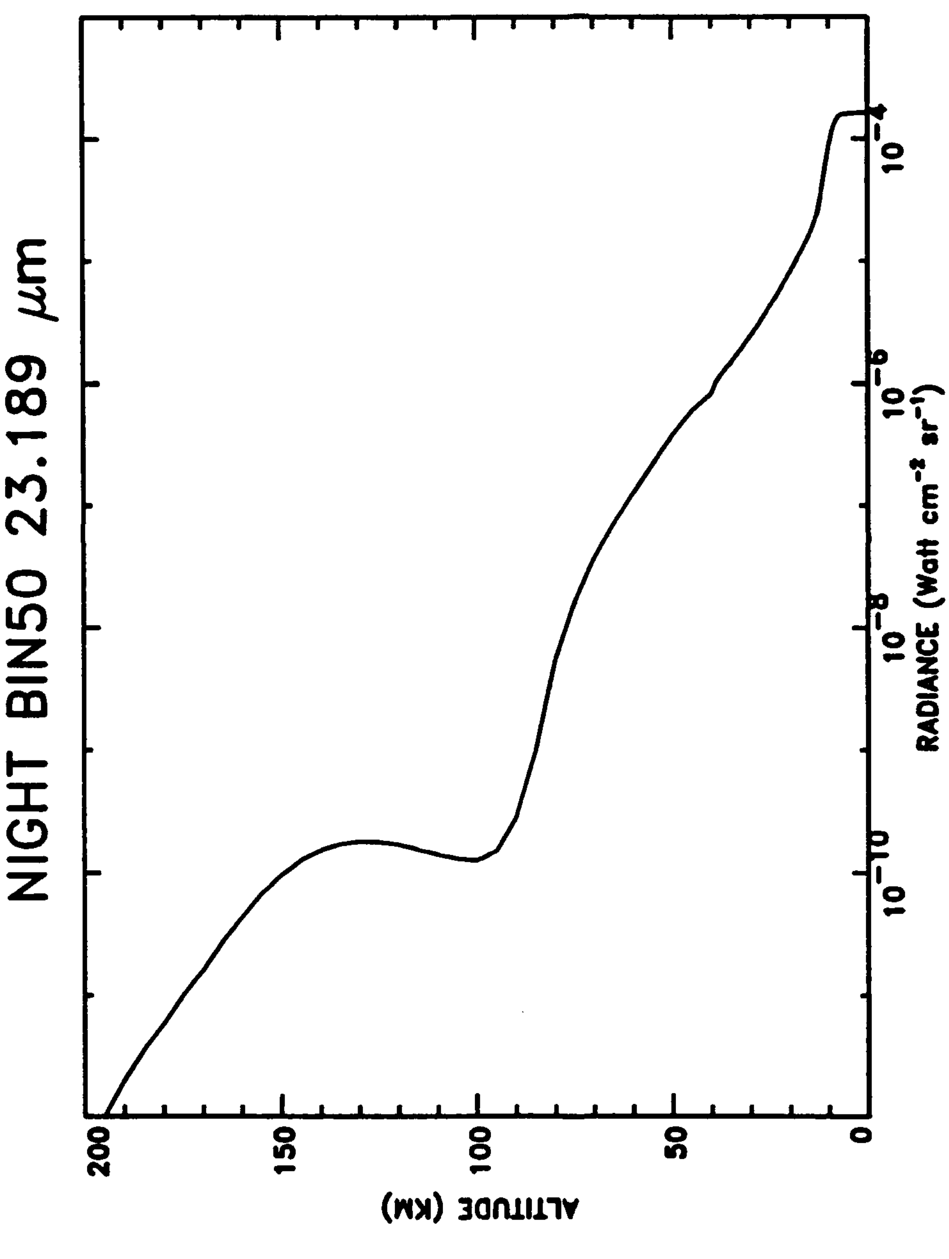

NIGHT BIN47 19.958 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴



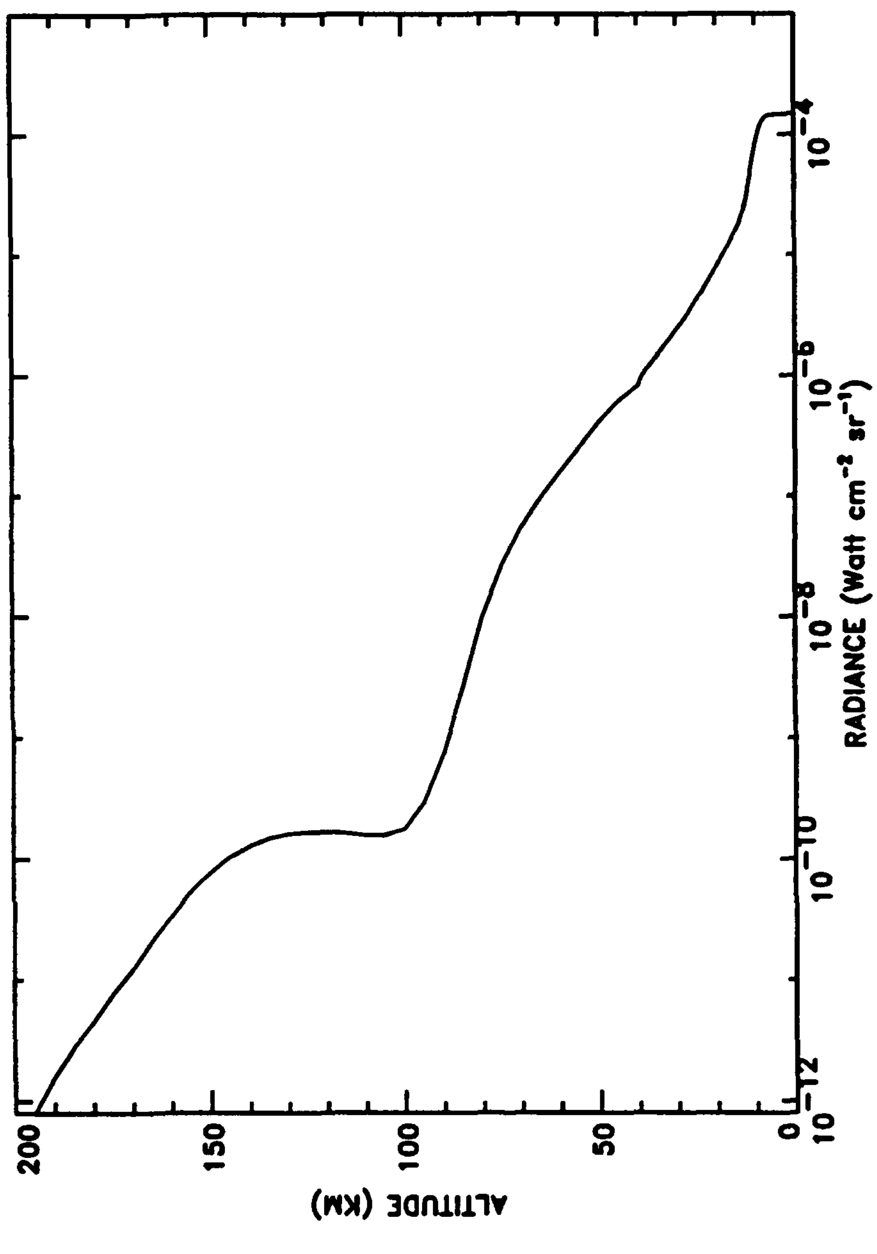
NIGHT BIN48 20.981 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

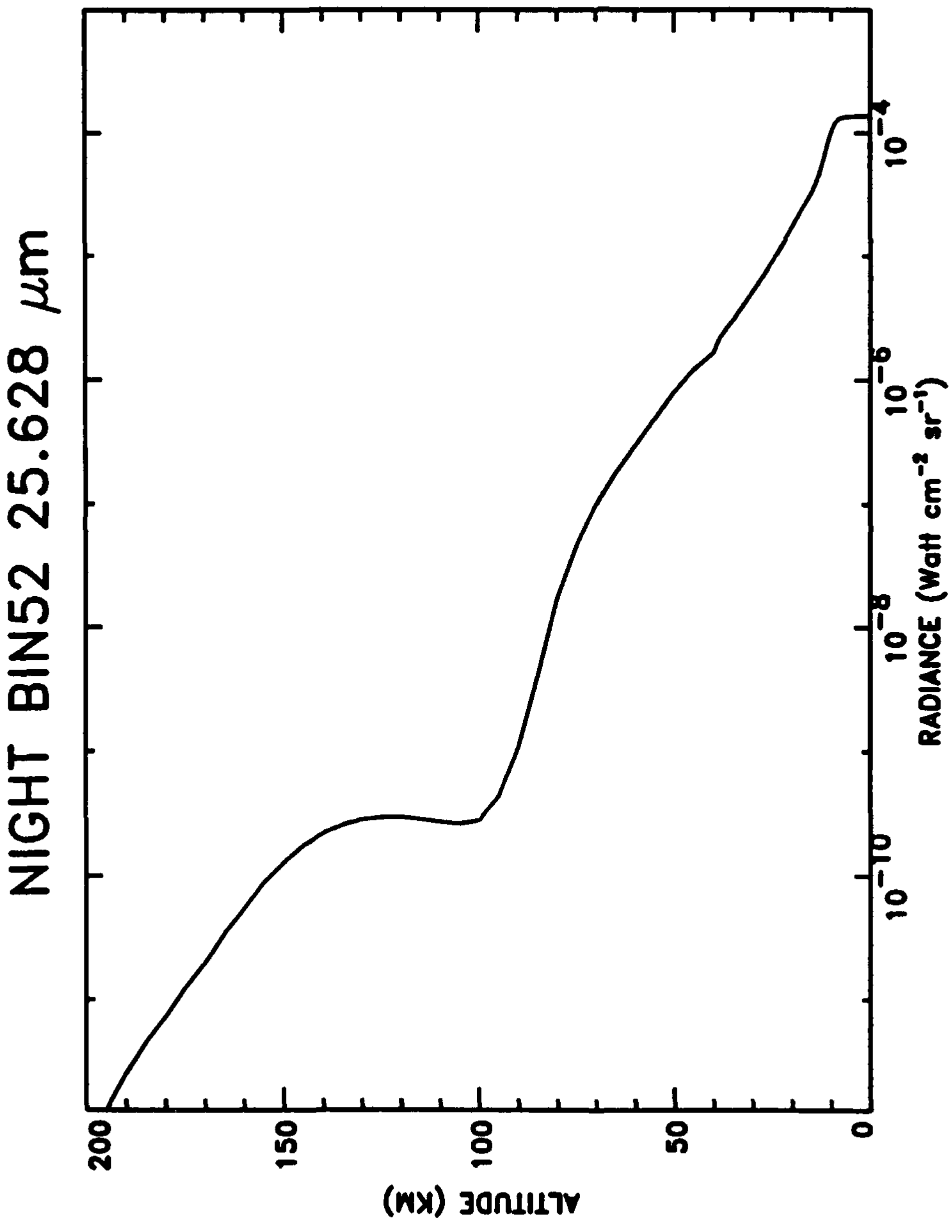
NIGHT BIN49 22.057 μm



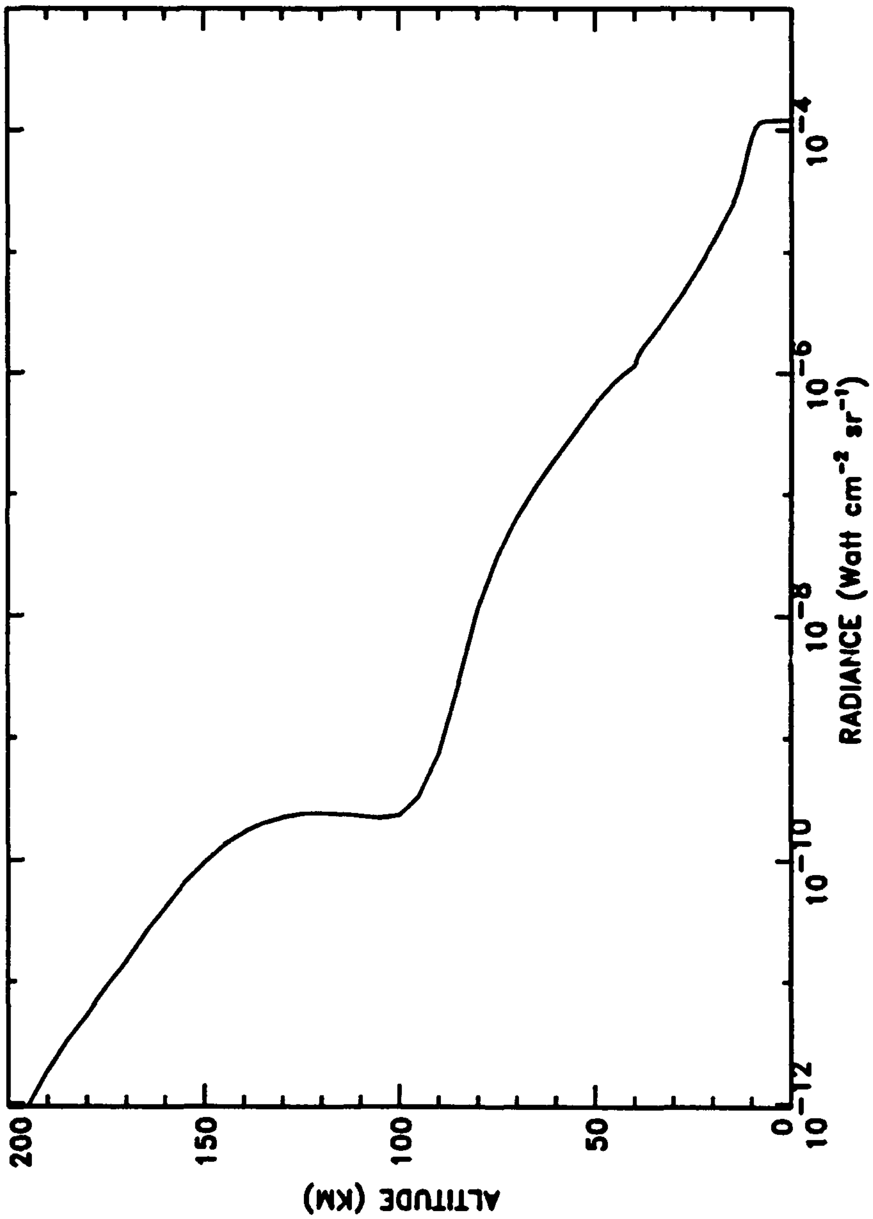

NIGHT BIN50 23.189 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

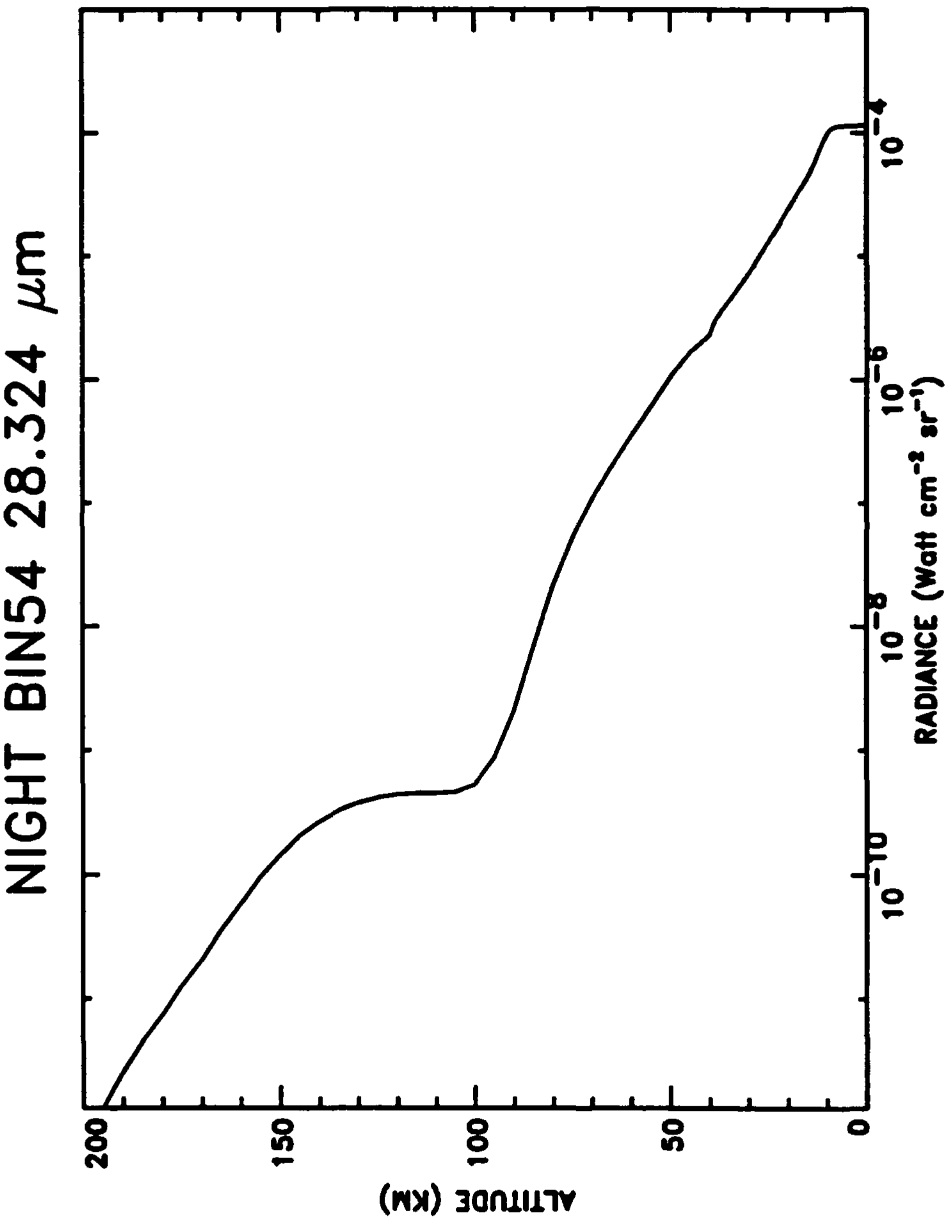
NIGHT BIN51 24.378 μm



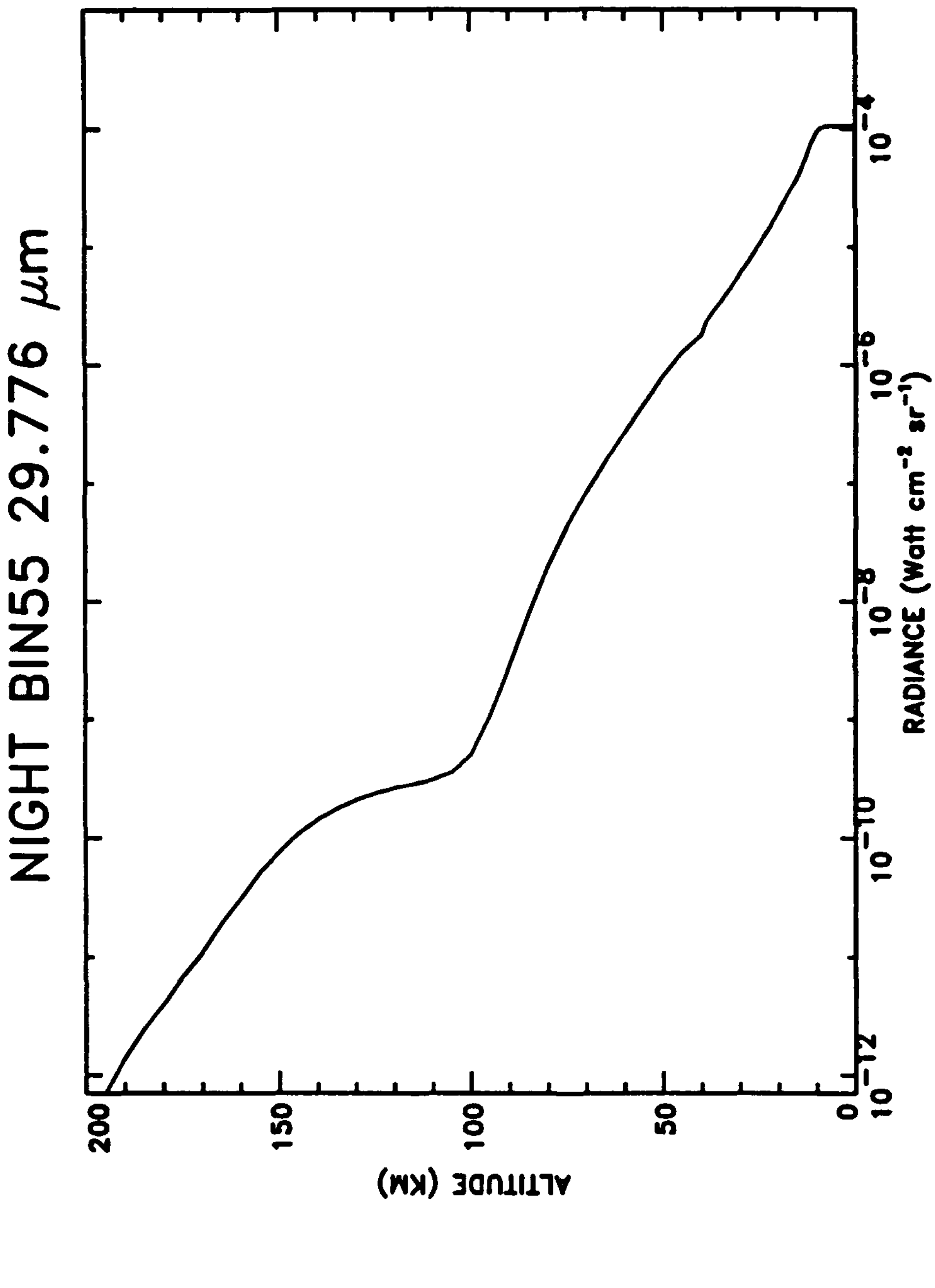

NIGHT BIN52 25.628 μm
ALTITUDE (KM)
0
50
100
150
200
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

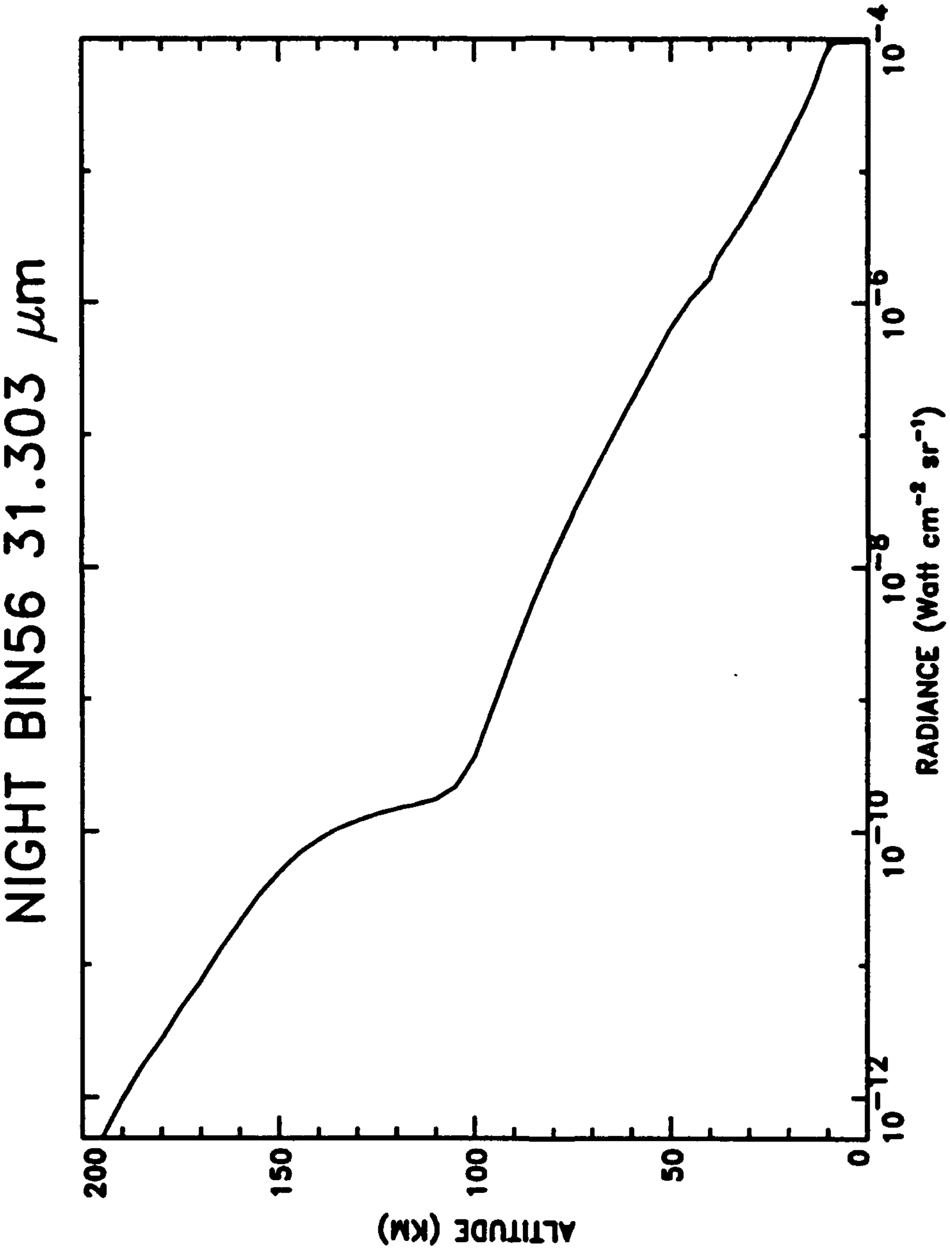
NIGHT BIN53 26.942 μm

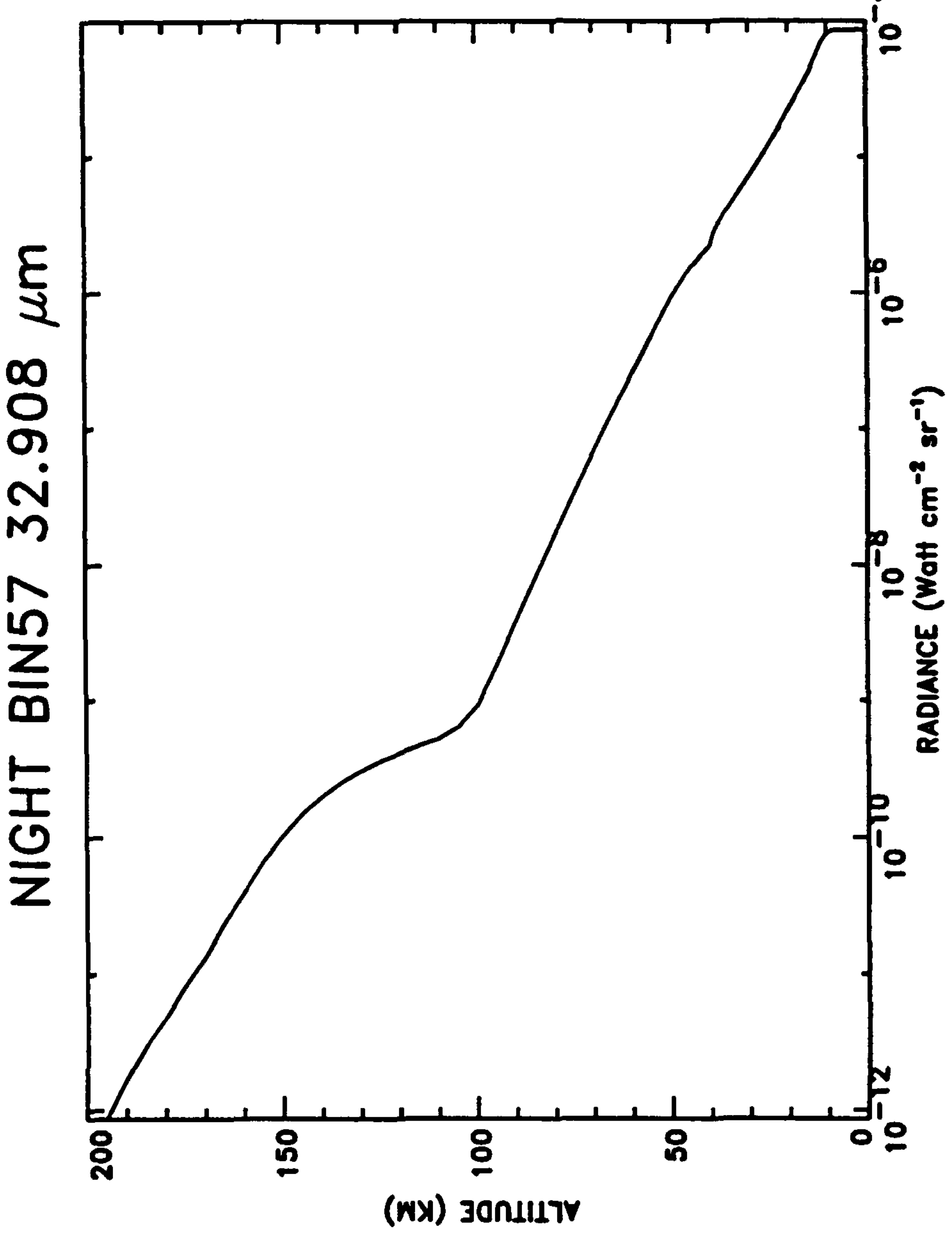




NIGHT BIN54 28.324 μm
ALTITUDE (KM)
200
150
100
50
0
10^{-10}
10^{-8}
10^{-6}
10^{-4}
RADIANCE (Watt cm^{-2} sr^{-1})


NIGHT BIN55 29.776 μm
ALTITUDE (KM)
RADIANCE (Watt cm⁻² sr⁻¹)
200
150
100
50
0
10^-12
10^-10
10^-8
10^-6
10^-4


NIGHT BIN56 31.303 μm
ALTITUDE (KM)
0
50
100
150
200
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴


NIGHT BIN57 32.908 μm
ALTITUDE (KM)
200
150
100
50
0
RADIANCE (Watt cm⁻² sr⁻¹)
10⁻¹²
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴

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